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# GLOBAL CLIMATE CHANGE (GCC) ISSUES AND THEIR IMPACTS ON THE US ARMY CORPS OF ENGINEERS

US Army Corps of Engineers
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TEC-SR-1

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This report is a survey of recent findings and arguments within the scientific arena on the subject of global climate change. The focus of this report looks at global, continental, and regional issues, as well as surface and upper atmospheric effects. Potential responses by the biosphere as well as the impacts on Army operations by global climate change are examined.

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# GLOBAL CLIMATE CHANGE (GCC) ISSUES AND THEIR IMPACTS ON THE US ARMY CORPS OF ENGINEERS

# EXECUTIVE SUMMARY

The greenhouse effect is an issue that has been greatly debated, misunderstood, and inappropriately blamed for recent extreme weather events. The greenhouse effect by itself cannot explain all the past, present, and predicted variations and trends in the world's climate. There are many other physical, chemical, and biological processes and interactions that influence the Earth's climate system. Some of the more important issues about global climate change (GCC) are the following:

- The geologic past provides a detailed record of Earth's climate system. It also reveals the changes that took place in the concentration of atmospheric gasses as Earth's climate switched from glacial to interglacial periods.
- The secular record of temperature shows that Earth's climate has warmed from 0.5°C to 0.7°C this past century. This record by itself does not demonstrate that the warming is attributable to an enhanced greenhouse effect, as the observed change is within the realm of natural variation.
- The world's populace is injecting tremendous amounts of greenhouse gasses into the atmosphere at a rate where the effective doubling of pre-industrial carbon dioxide ($CO_2$) concentration could occur between the years 2035 to 2050 (assuming no changes in present trends of human activities).
- General circulation models (GCM) show that the world's average change in temperature based on an effective doubling of atmospheric $CO_2$ concentration could be between 2°C to 5°C. There is no general agreement between the GCM's on other variables that are computed (i.e. precipitation, humidity, winds, solar radiation, and others). The accuracy of the models has also been questioned due to the simplistic modeling of several complex processes in the Earth system (i.e. biosphere and geosphere) that directly influence climate.
- Recent research on GCC shows that many factors have an indirect or direct effect on keeping the Earth cool. The clouds have been found to have a net cooling effect on the global average temperature. Anthropogenic pollutants and gasses produced from biological sources may increase the amount of clouds around the world, thus adding to the cooling effect.
- There are segments in the Earth system that tend to retard global warming, such as the aftereffects of a volcanic eruption, and gasses emitted by phytoplankton that lead to cloud formation.

- Scenarios of regional impacts from GCC have been developed by coupling GCM's with higher resolution regional models. These scenarios have shown that the southern and gulf coasts of the United States are at risk of enduring great hardships associated with rising sea levels as Earth's climate warms. There may also be considerable competition for water rights across the country. Current water management systems may reach a premature state of obsolescence as a result of GCC. Other areas that had once relied on rain may need water delivery systems to support current agricultural and community development programs.
- The Bush Administration proposed to budget 2.416 billion dollars in FY 1992 to research GCC. The committee responsible for overseeing the funding of this research is the Committee on Earth Sciences (CES).
- There may be increased pressure on developed countries to share liberally their energy-producing technologies with developing countries. This effort could minimize further damage to Earth's climate system in the immediate future. The alternative could be increased levels of anthropogenic greenhouse gasses being injected in the atmosphere by developing countries attempting to reach economic parity with developed countries. Undeveloped countries may be under increased stress to supply just the basic supplies for subsistence of their populace in a warming environment.
- The U.S. Army Corps of Engineers (USACE) in its mandate under AR 10-5 will come under increasing pressure to protect federal and privately held buildings and lands.
- Weapon and support systems may require upgraded data bases to match vegetation changes due to evolving climate patterns. Qualitative analysis and preventative maintenance procedures will have to account for changing ph values and increased air/water pollution indices.

There is a concerted effort nationally and internationally to fund more research on GCC so that more accurate scenarios on future climate can be achieved. One of the more ambitious programs is National Aeronautics & Space Administration's (NASA) Mission to Planet Earth program. Several Earth probes, polar orbital satellites, and geostationary satellites will be launched in this decade and the next. All of these space platforms will form a complete observing network of Earth's climate system and will enhance the understanding of how all elements in the Earth system contribute to and are influenced by GCC.

# PREFACE

This paper is the culmination of tasking to investigate the research that has been concluded recently and planned in the near future on global climate change (GCC). A literature review was conducted that focused on the current research and findings on the physical, chemical, and biological processes and interactions involved with GCC. This report lists our findings on GCC, and identifies some important issues that could have significant impact on the operations of the Corps of Engineers and the Department of Army.

The authors wish to thank Dot Murphy and Alison Whitmarsh for their assistance in assembling the information and to Paul Krause and Mark Flood for reviewing the report.

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Colonel David F. Maune, EN, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the U.S. Army Engineer Topographic Laboratories during the report preparation.

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# INTRODUCTION

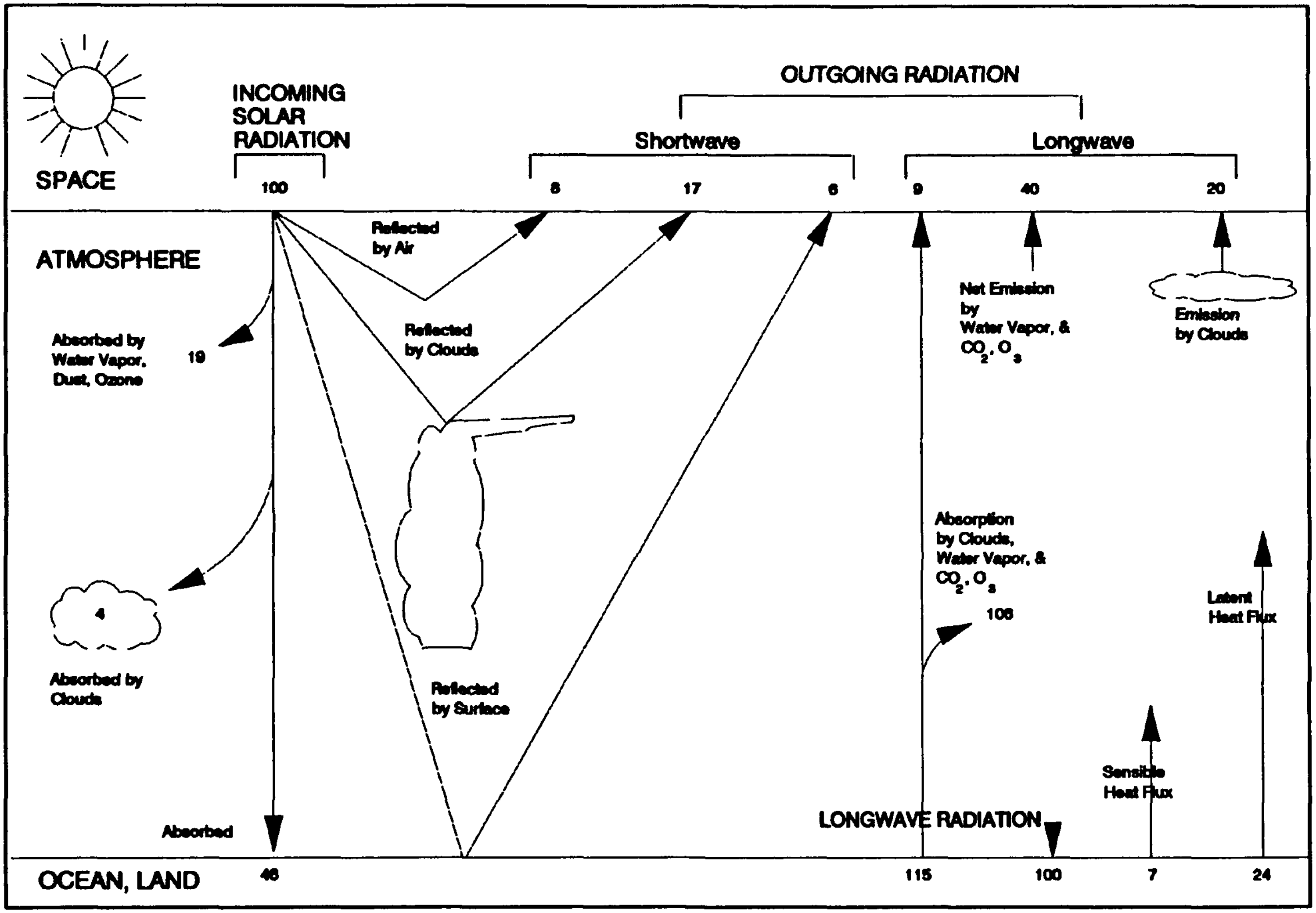
## Background

The greenhouse effect is the aggregation of processes that absorb and reflect radiation in its various forms, that modulates Earth's climate from a true black body state. The greenhouse effect has become an emotionally charged issue throughout the world during the latter half of the 1980's. This may be due to rising global temperatures and droughts in several parts of the world. The problem has been further exacerbated by rising confusion over what the greenhouse effect is, what signal indicates that this effect is intensifying, and how the greenhouse effect influences and is affected by other global processes in the Earth's system.

The greenhouse effect, which has always been active, is the reason for our world being habitable. Figure 1 provides a simplistic view of how incoming solar radiation is absorbed and reflected by the Earth's system. The units in the figure are expressed as a percentage of incoming solar radiation. Without the current concentration of greenhouse gasses in the atmosphere, the world's average temperature would be -18$^{\circ}$ C (-0.4$^{\circ}$ F). In a greenhouse environment without the modifying effects of the oceans, clouds and other biogeochemical feedbacks, Earth's surface temperature would rise to 72$^{\circ}$ C (161.6$^{\circ}$ F) [1-1]. The world's average temperature is presently about 15$^{\circ}$ C (59$^{\circ}$ F). The atmosphere's general circulation pattern and convective activity are the principle mechanisms that moderate Earth's climate between the two extremes.

There are many laypeople and some scientists who assume that the 'greenhouse' effect is now having a more adverse impact on Earth's climate than at anytime in recent history. They tend to blame any extreme weather event on the greenhouse effect. It is believed by some that in 1989 Hurricane Hugo was made stronger because of the greenhouse effect. This effect was also blamed by others for two extremely intense storms that hit England in the winter of 1989-1990. These two storms were stronger than any other storm for over a century [1-2]. Even the 1988 U.S. heat wave was attributed to the greenhouse effect by an expert witness during Congressional hearings [1-3]. None of these arguments stand on their own merit to prove the occurrence of a heating climate. However, there may be a growing tendency to assign capriciously the occurrence of isolated extreme events to the greenhouse effect without rigorously determining causality.

Neither isolated and extreme weather events nor an apparent warming in the world's temperature record can be used as the sole criteria to determine if the green-




(Source: Adapted from Smith and Tirpak, 1989)

Figure 1: Earth's energy balance

house effect is running rampant. Rather, it is the existence of long-term, wide-ranging, and permanent changes within Earth's geological-biological-climatological systems that may show the existence of permanent climate change. These changes should be visible in the migration of plant and animal life, changes in long established ecosystems, different precipitation patterns, evaporation and creation of lakes, and in many other systems and processes in the Earth's system.

Concentrating on the greenhouse effect alone does not fully encompass all that needs to be addressed with regard to the Earth system in a warming climate. Global and regional changes are expected in the hydrosphere, the biosphere, the oceans, and most other elements on Earth. Profound impacts on human activities may result if significant and rapid changes in Earth's climate occur. Although these changes will benefit some areas of the world, severe hardship will occur to other areas. Considerable effort, therefore, needs to be focused on studying climate change and its impact upon Earth's system, upon its interactions with subsystems within Earth's system, and upon humanity.

The subject of climate has always had its share of debates as compared to other scientific disciplines. Although world debate today centers on how warm temperatures will be by the middle of the next century, it was just 10 to 20 years ago that there was serious concern that we were entering into another ice age. For that brief period the average annual global temperature was declining. Was the reaction to the decline of the world's average temperature a myopic view of Earth's temperature record? Is the international debate on global warming another case of shortsightedness? The answer to the first question is most likely yes, but to the second is a qualified no. Anthropogenic influences, changes in Earth's system caused by human endeavors such as the emission of greenhouse gasses into the atmosphere, may force Earth's environment toward a warmer climate.

The discovery that the ozone layer is being destroyed by elements whose source is completely attributable to human activities probably forced global climate change onto center stage in world affairs. If humans can produce chemicals that can weaken or even destroy on a global scale one element in the Earth system, then what other actions are being done that will cause unexpected and unwanted changes in the future? Now that the world's societies have had decades to expel vast amounts of various gasses and other forms of pollutants into the Earth system, we can no longer extrapolate the past century of climate records to predict future climate. Mankind's impact on the Earth system must now be considered. This is particularly true when plans are made for systems, buildings, or equipment that have total life cycles that span decades.

Considerable effort is now underway internationally to understand and model climate change. Earth's climate has fluctuated greatly throughout recorded history and on geologic time scales, both globally and regionally. Expanding our knowledge of Earth's climate system involves the study of ice cores, and sediments on ocean and lake bottoms. The general circulation models (GCMs), which model Earth's climate system, have been evolving to incorporate the many new findings of the past 20 years. Yet, they still need to be improved. The models are using a very coarse grid over the globe and some oversimplified permutations of important interactions in the Earth's system. The GCMs provide us with a blurry view of future climate. Still, this lack of realism should soon be resolved due to the current level of scientific research efforts.

Part of the effort to improve our understanding and modeling techniques is to enhance current observation systems and to develop new space-based observation platforms. Past land-based observations had limited use because many measuring instruments were moved. When moved, the instrument's data history may show an artificial change in a positive or negative trend in the parameter (such as temperature) being measured. Such is the case when instruments are initially located near or within a city. Over time the uncorrected temperature readings would show a warming bias due to the "Urban Heat Island Effect." Then, when the instrument is moved to outside the city the data trend measured by the instrument shows an immediate and artificial cooling effect. This effect is easily demonstrated in historical records. As a result, elaborate data filters had to be developed to diminish the skewing of results in studies that rely on this data.

Space-based observational platforms constitute the major thrust in our national effort to understand global climate change. NASA has proposed an aggressive program called 'Mission to Planet Earth' that is intended to provide constant monitoring of the Earth's system by several space platforms. Linking the space and land observation systems will provide an excellent means to measure changes in climate and to calibrate the GCMs.

## Purpose

Climate change, as it is now projected, is expected to affect the world's and especially the United States' environment in many ways. The U.S. Army and the Corps of Engineers will have much to be concerned about in the coming decades. For example, changes in sea level will affect U.S. wetland management practices, such as redefining what constitutes wetlands. With a rising sea level, there may be lands that are set aside for development, which could fall under wetland management guidelines due to an encroachment of wetlands. In addition, reduced rainfall in parts of the country may force modification or abandonment of current water projects. In contrast, other parts of the United States may have improved agricultural and hydrographic conditions. As a result, new water management systems may have to be installed in areas where they presently do not exist.

Another area of concern is the willingness of the general public to adapt or accept changes in their current way of life forced on them by climate change. If global climate change were to occur at a rapid rate, efforts to adapt or mitigate the change may be met with stiff resistance from the public due to extraordinarily high costs associated with an accelerated response by the government.

## Scope

Available information indicates that we may be in the midst of a warming climate. This paper will discuss many issues, studies, and problems associated with global climate change, and will report on the important impacts of these changes on the world, for the United States, and specifically for the U.S. Army and the Corps of Engineers.

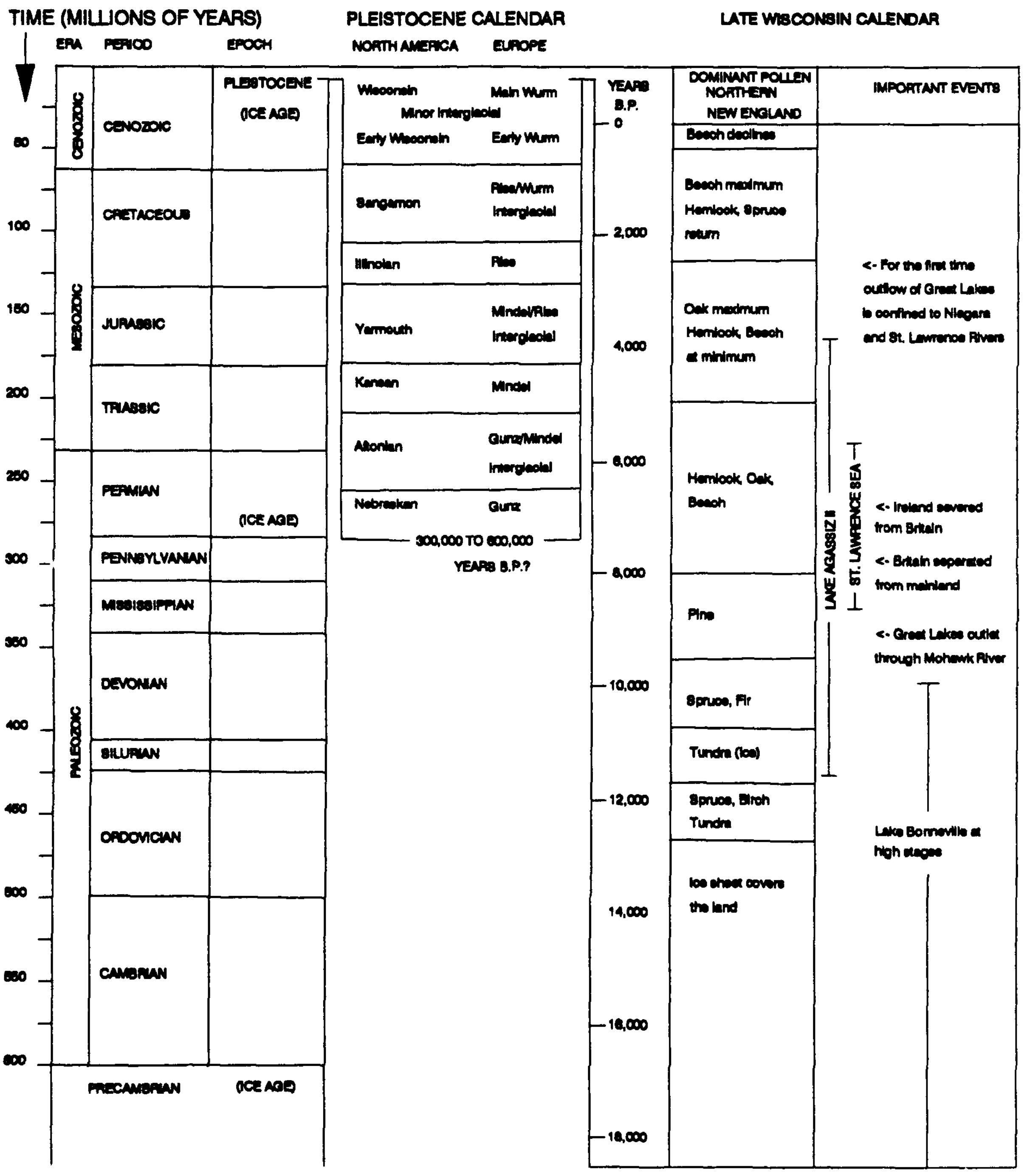
# THE GEOLOGIC RECORD

The old adage "that history often repeats itself" suggests that the pattern of weather events associated with global climate change (GCC) should have some basis in past events. One of the more accurate methods devised to date involves the inspection of our cyclic glacial past through the analysis of ice cores from Greenland, the Arctic, and Antarctica. This is a logical extension of the works produced by Dr. Louis Agassiz and the mathematician Milutin Milankovitch to show that the Earth's orbit, its axis tilt, and its rotational wobble superimpose a pattern of 18,000 year, 23,000 year, and 41,000 year cycles on top of a primary 100,000 year cycle to explain the glacial and interglacial periods in the earth's past. The interglacial periods are relatively short. Their normal time span is between 9,000 and 12,000 years. Climatologist Reid Bryson believes our current interglacial period has been with us for about 10,800 years [2-1]. So we effectively have a 1,200-year time window in which to operate before the next glacial epoch slowly wipes the slate clean. To date, a combination of ice cores and ocean floor sediment cores have been analyzed to produce a record of the last 800,000 years. This is done primarily through the comparison of oxygen molecules, $O_{16}$ to $O_{18}$ [2-2]. The breakdown of these glacial-interglacial periods is illustrated in the geologic time map shown in figure 2. The period in which many important events occurred in the late Wisconsin are displayed on the right-hand side of the time map.

The characteristic time scales over which causes of climate change take place are shown in figure 3. The many elements in climate fluctuations are illustrated within the body of the graph, and the length of time over which they occur are shown at the bottom. Other factors that impact on climate are also shown, such as human activities, internal process, and external processes. It is evident from figure 3 that human activities do have an impact on climate, though their duration is far less than almost any naturally occurring variation.

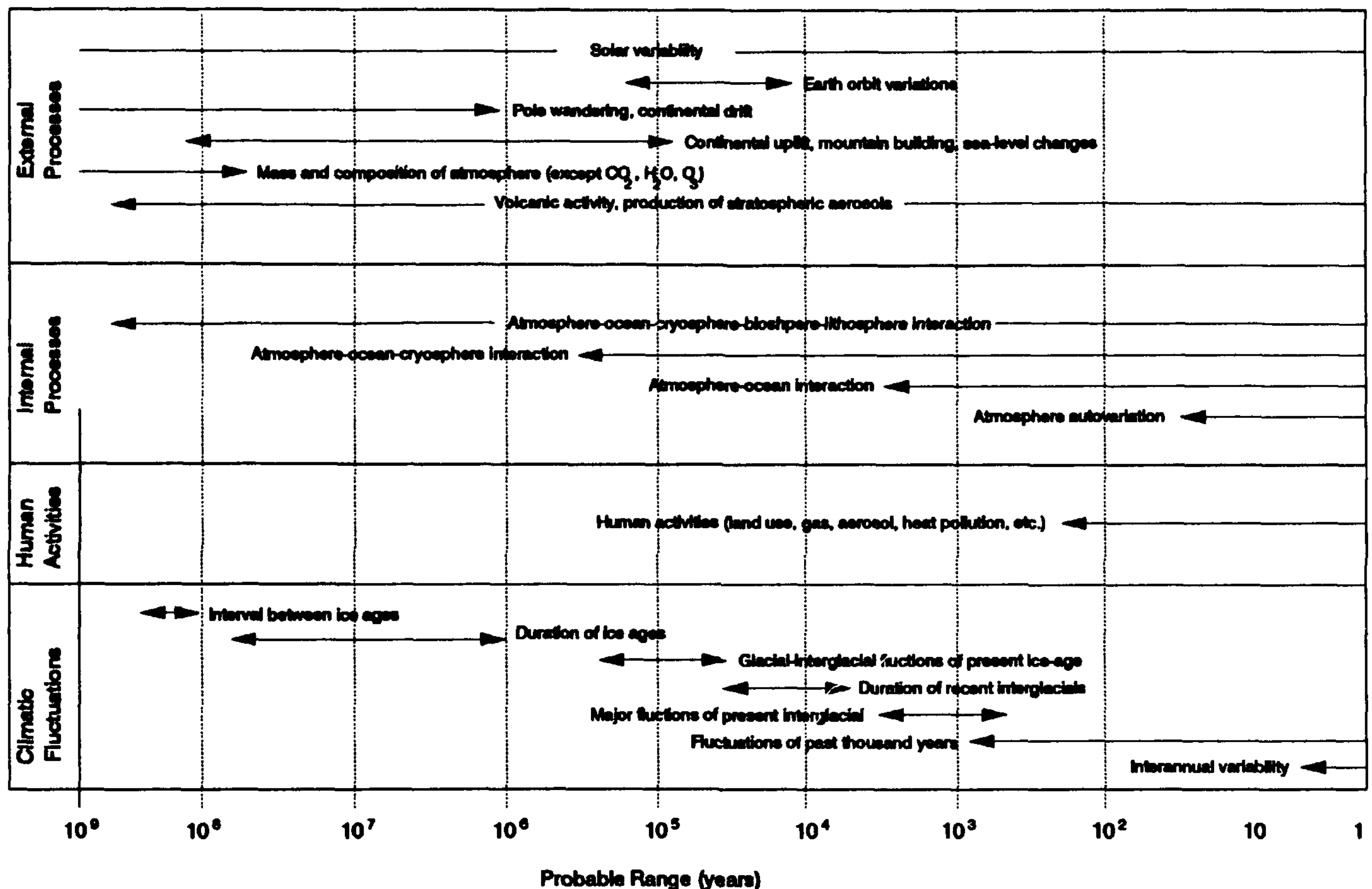
Other methods of fine tuning this historical record include the analysis of carbon dioxide in air bubbles trapped in these ancient ice cores [2-3]. Other contributing factors are the varying amounts of methane, dust, pollen (particularly from the Dryas flower), and cadmium. With the exception of cadmium, the other elements fulfilled a dual role by acting as a natural atmospheric pollutant, and by also influencing cloud formation, density, and length of duration per occurrence [2-4,5].

Cadmium by itself has no effect on glacial or interglacial formations; but it does serve as a tracer for studying deep ocean water cycles. It has been shown that the deep water cycles for conducting heat to the surface and its subsequent release in the air over the North Atlantic accounts for "about (30) percent of the yearly direct input of




(Source: Adapted from Dyson, 1962)

Figure 2: Geologic time map.




(Source: Adapted from World Meteorological Organization, CSM R84/86)

Figure 3: Characteristic time scales over which causes of climatic change take place.

solar energy in that region. This should not be confused with the heat transport mechanism associated with the Gulfstream which is operating further south over the central North Atlantic. Thus when this conveyor belt of deep water heat flow is cut off, an abrupt change to a much cooler climate for North America and Europe can quickly occur "[2-6].

One of the possible methods for turning this deep water cycle on and off is based on North American geography. As the last major ice age was ending about 14,000 years ago, the fresh water melt was flowing at a rate similar to today's Amazon River flow. At first this flow was channeled down the Mississippi River to the Gulf of Mexico:

> "... about 11,000 years ago, however, a major diversion sent meltwater in torrents down the St. Lawrence River to the Atlantic.
>
> A vast clearinghouse for meltwater, known as Lake Agassiz, had formed in the bedrock depression at the edge of the retreating ice sheet in what is now southern Manitoba. Until 11,000 years ago the lake, larger than any of the existing Great Lakes, had overflowed a bedrock lip to the south and drained down the Mississippi. Then the retreat of the ice opened a channel to the east. The water level in Lake Agassiz dropped by 40 meters as water flowed across the region of the Great Lakes and down the St. Lawrence.
>
> Foraminifera (fossil evidence of microorganisms that inhabit water masses of specific temperature and salinity) from surface waters of the Gulf of Mexico record this diversion. Their $O_{18}$ content had been anomalously low, reflecting the $O_{16}$-rich meltwater discharging from the Mississippi. About 11,000 years ago, the isotopic ratio increased abruptly as the Lake Agassiz diversion shut off the meltwater flow to the Gulf.
>
> The meltwater, meanwhile, poured into the North Atlantic close to the site of deep-water formation. There it reduced the salinity of surface waters (and hence their density) by so much that, in spite of severe winter cooling, they could not sink into the abyss. The conveyor belt stayed off until 1,000 years later, when a lobe of ice advanced across the western end of the Lake Superior basin and once again blocked the exit to the east. Lake Agassiz rose again by 40 meters, diverting the meltwater back down the Mississippi. The conveyor belt was reactivated, and Europe warmed up again. This time span known as the Younger Dryas links freshwater flow, ocean circulation and climate--but only regional climate. Sharp cooling was only evident in North America; elsewhere its effects were slight or absent" [2-7].

Another method used to verify results of ice and ocean sediment cores are sediment cores taken from various lake bottoms in order to analyze pollen levels. This gives an accurate assessment of grass, flowers, and tree species migration levels as ice boundary lines waxed and waned north and south with the passage of time. A general rule-of-thumb appears to be that a "vegetation change generally lagged behind the initiation of a climate change by 50-100 years" [2-8].

As a further focus on current conditions, pollen and sediment records can be tied into tree ring records (both current and fossilized) to produce an accurate record for the last 8,200 years. This type of study is known as Dendrochronology [2-9]. Dr. Edmund Schulman, a dendrochronologist at the University of Arizona, in the summer of 1957, analyzed a tree core taken from a California, White Mountain, bristlecone pine tree and was able to accurately count growth rings back 4,600 years. This coupled with fossilized tree ring samples pushes the time line back 8,200 years. This is considered to be the edge of the last ice age [2- 10].

Another form of accurate archival dating is accomplished by tracing the half life series of Carbon-14 as it disintegrates back to a more normal Nitrogen-14. Radioactive Carbon-14 has a half-life of 5,700 years, and can be used for a tracer element back to 70,000 years ago. Other tracer elements are used out to about 100,000 years ago [2-11].

Thus in a broad brush approach, a record can be followed for the last 80,000 to 100,000 years. A more definitive record of climatology can be inspected for the last 8,200 years, and a rather detailed record can be observed and tested for the last 200 years.

Unfortunately, there is one flaw in this scenario. With the exception of the last 100 years, most of the data, traces, and clues refer to events on land or in the water. Until the turn of the century, no real data or evidence is available to produce a focused portrait of what was going on in the atmosphere before, during, and after each glacial-interglacial event. An understanding of previous atmospheric processes is vital to climatic change research. A definite area of scientific investigation would be in this vital area. If traces of data exist, we need to learn how to recognize them; and then how to understand their values. Land and sea interactions are also vital, but the necessary understanding will not be complete until Air-Land and Air-Sea interactions over the same time frame are analyzed, understood, and applied to current general circulation models (GCMs).

# THE SECULAR RECORD OF TEMPERATURE

The world's climate has changed significantly over the course of Earth's history, as shown in the previous chapter. Climatology is not static, but varies greatly when viewed over a long period of time. This leads to the question, can human activities induce an accelerated response in the climate system that exceeds the observed record? Research is being conducted to answer this question.

## The Instrument Record

One clue that could help unlock the answer to the above question is the instrument-recorded surface temperature series. The study of the surface temperature profile for the past century has become one of the most heavily researched topics in climatology. This record provides an objective look at what has happened to Earth since the dawning of the industrial age. Nevertheless, there is disagreement in the interpretation of the data. Papers have been written that suggest the existence of the greenhouse effect, while others have analyzed the same data to show that there is no consistent trend.

The unmodified temperature record for the past century is unfortunately replete with errors, omissions, and unrealistic trends of what changes have occurred to the free air environment. In its raw form, the temperature data over its entire history suffered from scribble errors, keying errors, misread instruments, and more. Much research and work was needed to improve on the data set, identify and correct the errors, and account for systematic biases. The many attempts to identify and correct these errors have reduced them to a minuscule amount. The National Center for Atmospheric Research (NCAR) maintains an improved data set in digital form.

Another problem is the displacement of temperature observing systems. The equipment used to record temperature may have been moved several times, such as from the roof of a building with an air conditioner to the middle of an airport runway. The result is a discontinuous record that could indicate a false trend in the temperature series. There is also little consistency nationally or worldwide as to the placement of temperature sensors.

The surface air temperature is further skewed toward a warmer climate as urbanization occurs. This is a well-documented phenomena called the heat island effect.

The temperature within the urbanized area can be several degrees centigrade higher than surrounding undeveloped areas.

The data base is also not complete. The surface temperature data base does not cover the entire world for the 100-year record. What does exist is a dense observation network over Western Europe and the East Coast of the U.S. from 1880 to the present. The spatial and temporal density of reporting stations in the U.S. diminishes from the East Coast to the West Coast.

The record shows a similar pattern in the Northern Hemisphere when a comparison is made between developed and developing countries. The spatial and temporal density of observations is greatest for the developed countries, and is minimal for the developing countries, and almost nonexistent for the undeveloped countries. The record also shows a greater number of observations for the Northern Hemisphere than for the Southern Hemisphere. Temperature data are also inadequate over water areas. Since data are only available where ships sail, much of the globe is void of meteorological observation.

Sea surface temperatures share the same problems in observations as the air temperature observations, with one added complication. Prior to 1970, measurements of sea surface temperatures were often taken by bucket. A seaman would throw a bucket overboard, than haul it back aboard and measure the water's temperature. After 1970, the practice of many vessels changed to reading the temperature of the intake water for the vessel's engines. The problem is that the water intake pipe is about 30 feet deeper than the depth where measurements were taken by bucket [3-1]. This variation is unfortunate, because sea surface temperatures, like land-based temperatures, are important to understanding and modeling climate change.

Because of the lack of data, interpretation of the little evidence that is available has been debated vigorously. For instance, a report from the National Oceanic and Atmospheric Administration (NOAA) showed that the world's oceans were warming by $0.1^{\circ}C$ per year from 1982 to 1988 based on satellite data [3-2]. This was soon refuted by others who pointed out that the data had not been filtered to account for a major volcanic eruption, nor the onset of a major ENSO event (El Nino, Southern Oscillation) during the observation period.

Still, other researchers found that the global average sea surface temperature did make abrupt changes over the past century [3-3]. General cooling occurred about 1900, and warming in the 1930's. There are many questions that must be answered about the relationship of the atmosphere and the oceans, and the ocean's response to a changing climate.

## The Global Temperature Series

Several worthwhile studies have been made on the world's average temperature, with very interesting results. One such study by Hansen and Lebedeff (1987) [3-4] provided a view of averaged temperatures on a global, hemispheric, and latitudinal scale. Their study detailed the behavior of the lower atmosphere, and how it has changed since 1880. Figures 4 through 14 show their results graphically. Each graph shows the actual data for land observations with the five-year-averaged mean superimposed.

The global change in surface air temperature from 1880 to 1985 is shown in figure 4. This graph shows that there has been no linear trend of increasing temperature for the period of record. Overall there has been a general increase in temperature of about 0.7°C. From 1880 to 1940 the trend was an increase of about 0.5°C, then a decrease of about 0.2°C from 1940 to 1965, and a general rise in temperature of about 0.3°C from 1965 to 1980. It is also worthwhile to note that the 1980's have been the warmest years on record.

Researchers at the United Kingdom Meteorological Office and the Climatic Research Unit of the University of East Anglia in Norwich, England, have conducted similar studies. They have collected their own surface observation data set which is independent of the one used by Hansen. The U.K. data set consists of weather observations of over 1,000 stations world-wide with records that exceed 100 years. Their data set also includes observations from ships at sea. The scientists at the University of East Anglia found that the averaged global temperature for 1988 exceeded the 30-year average (1950-1979) by 0.34°C [3-5]. They further reported that 6 of the 10 hot-

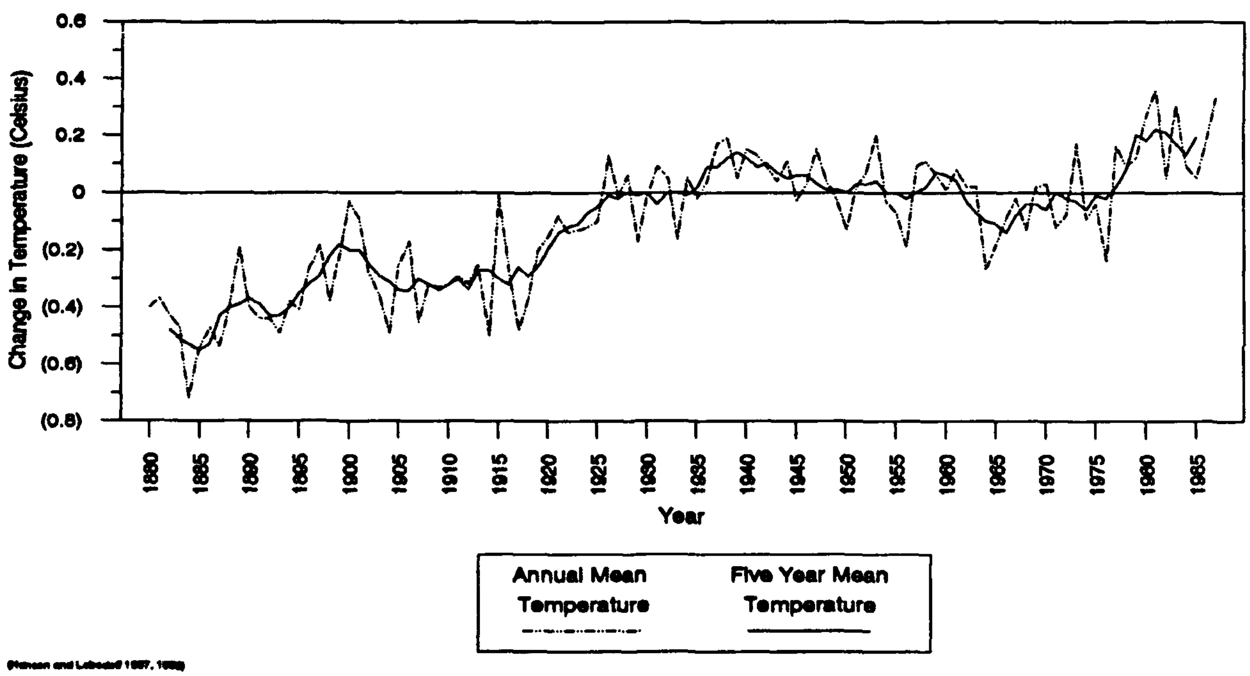



Figure 4: Global surface air temperature change

test years on record occurred in the 1980's. Following 1988, the second warmest year was 1987. The other top six warmest years ever recorded were, in order of decreasing temperature: 1983, 1981, 1989, and 1980. The years 1982, 1984, 1985, and 1986 were not among the warmest 10 years [3-6].

The Hansen study considered the global temperature for the Northern and Southern Hemispheres separately, as shown in figures 5 and 6. These figures show that the variability of the Northern Hemisphere mimics the global average temperature and is more changeable than the Southern Hemisphere. The Southern Hemisphere's average temperature change tends to be near zero, with less defined and less abrupt changes than the Northern Hemisphere. For example, the Northern Hemisphere showed a dramatic rise in temperature in the 1920's, while the Southern Hemisphere barely changed. A major factor for the observed difference in the temperature record between the hemispheres is the greater water surface area in the Southern Hemisphere. The oceans have great influence on a region's climate, and tend to mollify any dramatic swings that can occur over land.

The data were further divided into latitudinal bands for both hemispheres: from the equator to 24N/S; 24N/S to 44N/S; 44N/S to 64N/S; and 64N/S to 90N/S.

The surface air temperature between the equator and 24N in figure 7 shows little change for the entire period of record. A similar pattern for the 24N to 44N band, with

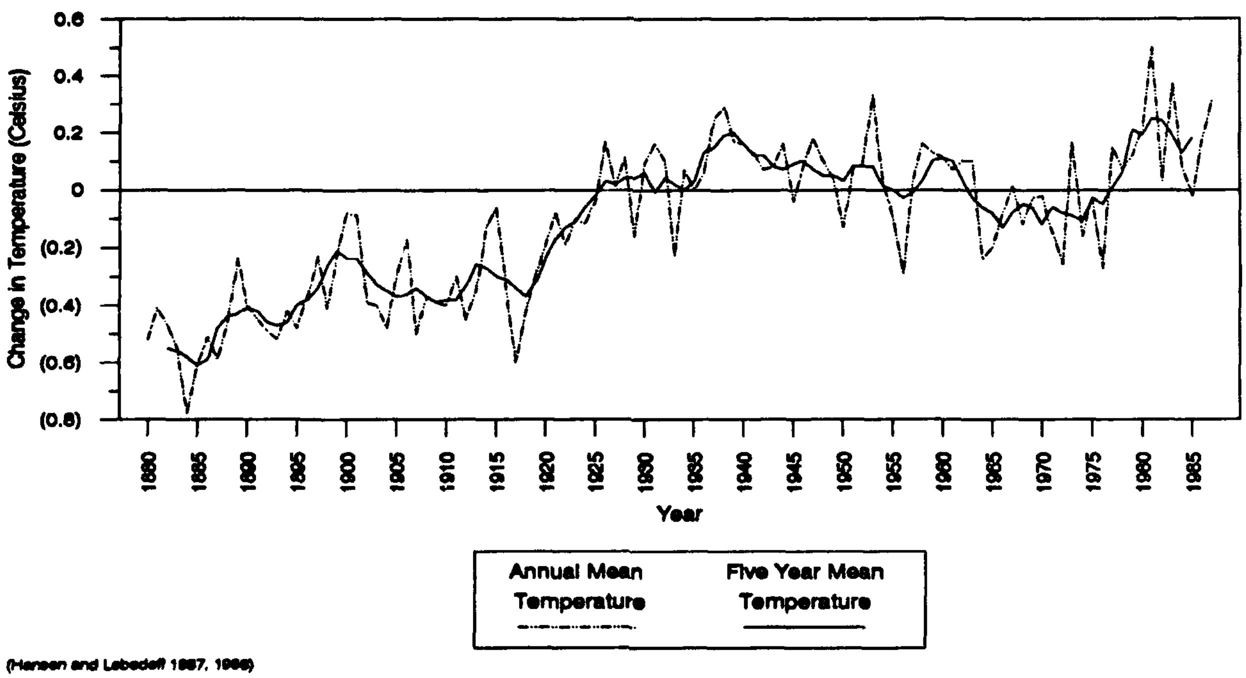
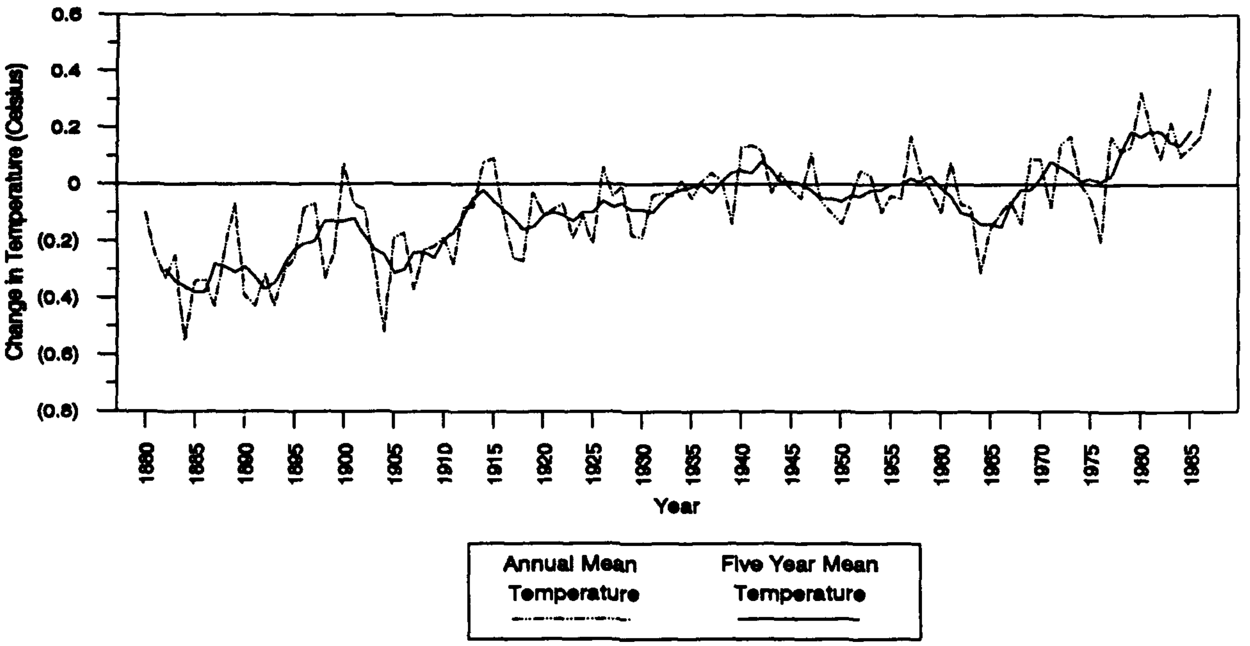



Figure 5: Northern Hemisphere surface air temperature change




(Hansen and Lebedeff 1987, 1988)

*Figure 6:* Southern hemisphere surface air temperature change

slightly more variability, is shown in figure 8. The 44N to 64N band shown in figure 9 begins to explain the variability of the Northern Hemisphere record. However, it is the 64N to 90N band displayed in figure 10 that shows the dramatic changes that have occurred in the atmosphere. The changes in temperature for the North Pole are far more dramatic than shown in either the Northern Hemispheric or global scale figures. The polar region tends to amplify any changes that occur in Earth's average temperature.

A similar pattern appears when the Southern Hemisphere is broken down into its latitudinal bands shown in figures 11 through 14. These differences are not as striking as those which appear in the Northern Hemisphere record. The variations in the Southern Hemisphere bands tend to gravitate around zero change. The South Pole, like the North Pole, has the greatest variation of any other southern latitude bands. Unfortunately there were few observations at the South Pole prior to 1957.

As global change occurs due to warming by an intensifying greenhouse effect, several patterns in the world's surface thermal structure are expected to occur. One in particular is that the polar regions should experience greater change in increased temperature than the middle and tropical latitudes. The Northern Hemisphere is also expected to warm more than the Southern Hemisphere. If the 1940-1965 period could be cropped out of the temperature record provided by Hansen and Lebedeff, then there might be a strong argument that the greenhouse effect is increasing. Instead, this period of time casts doubt that there is an intensified greenhouse effect.

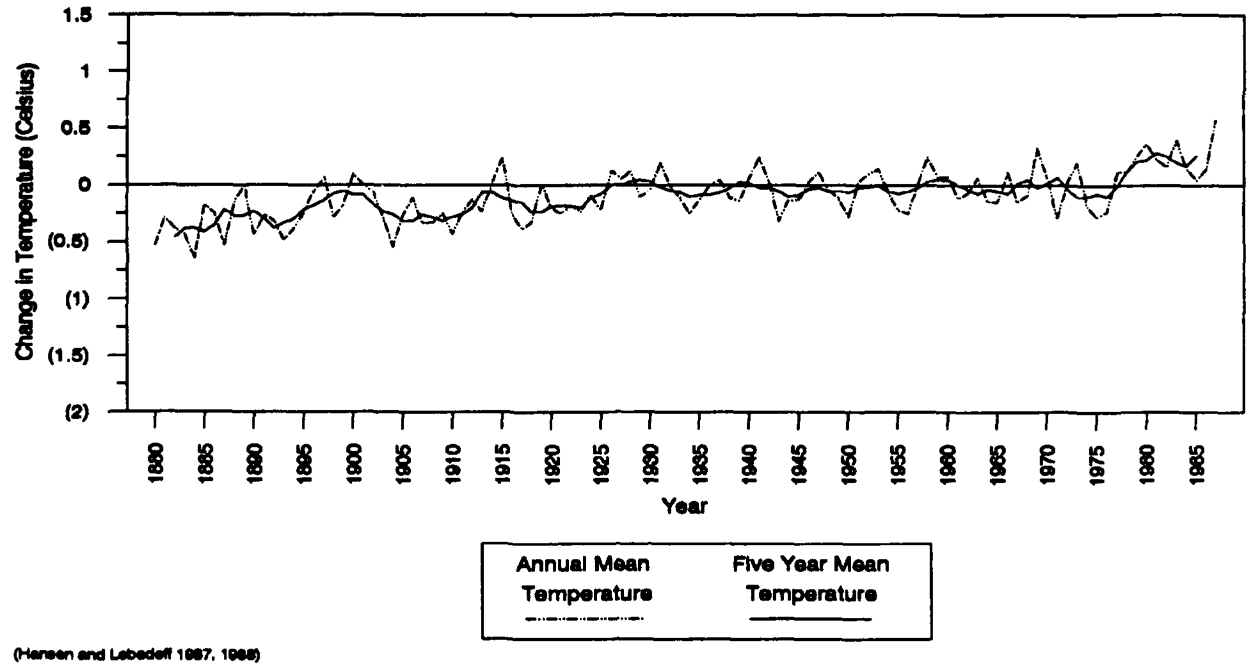



Figure 7: The equator to 24N surface air temperature change

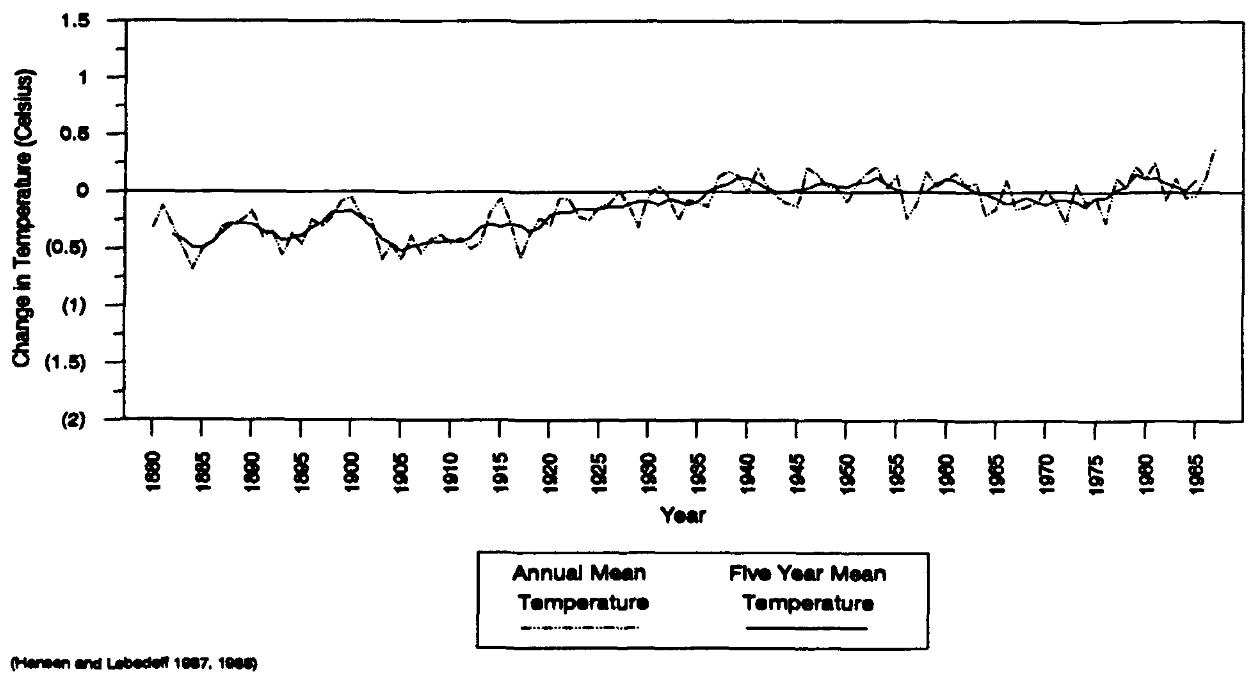



Figure 8: The 24N to 44N surface air temperature change

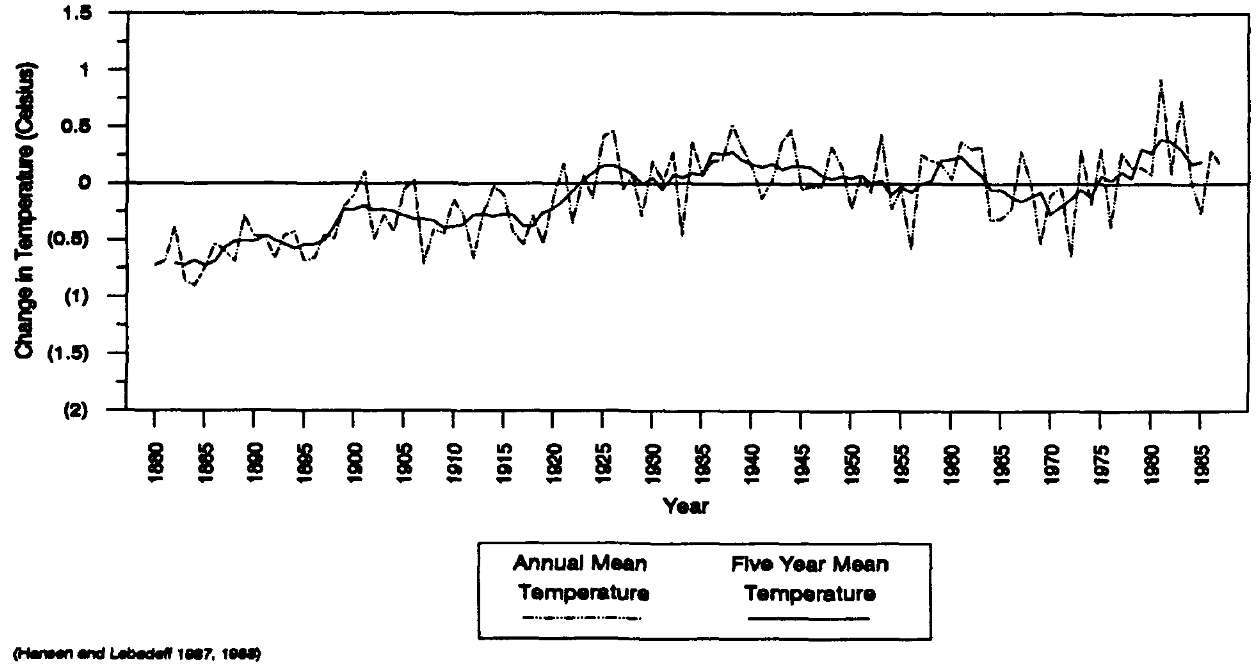



Figure 9: The 44N to 64N surface air temperature change

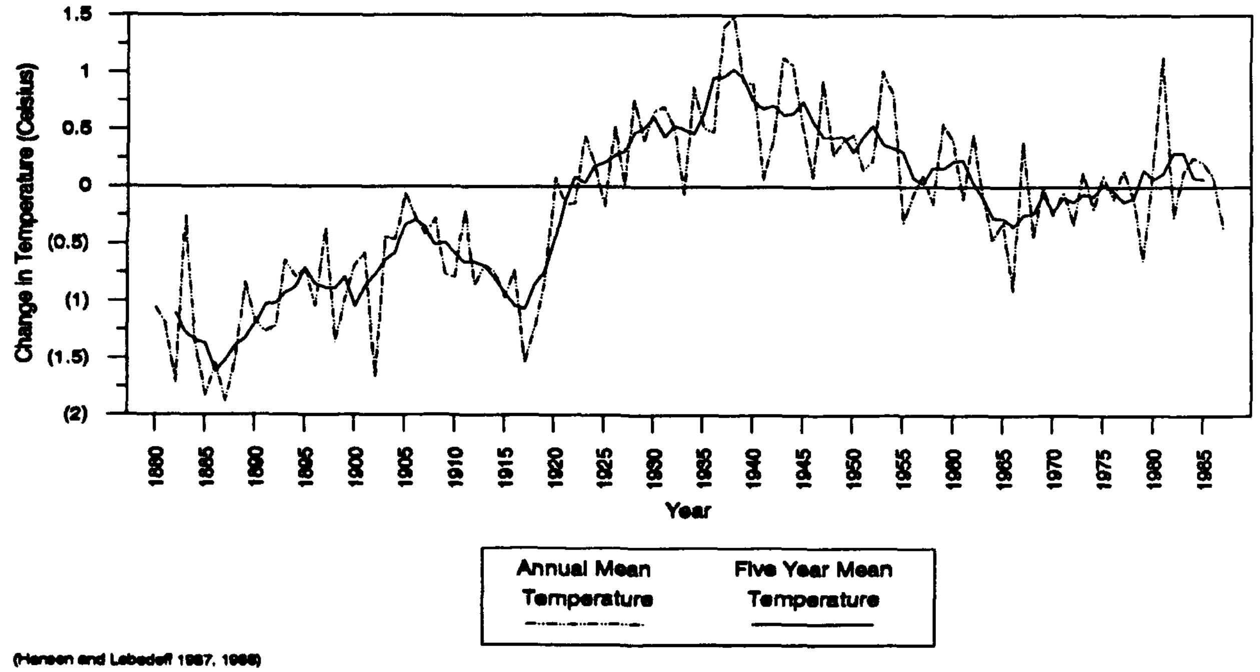
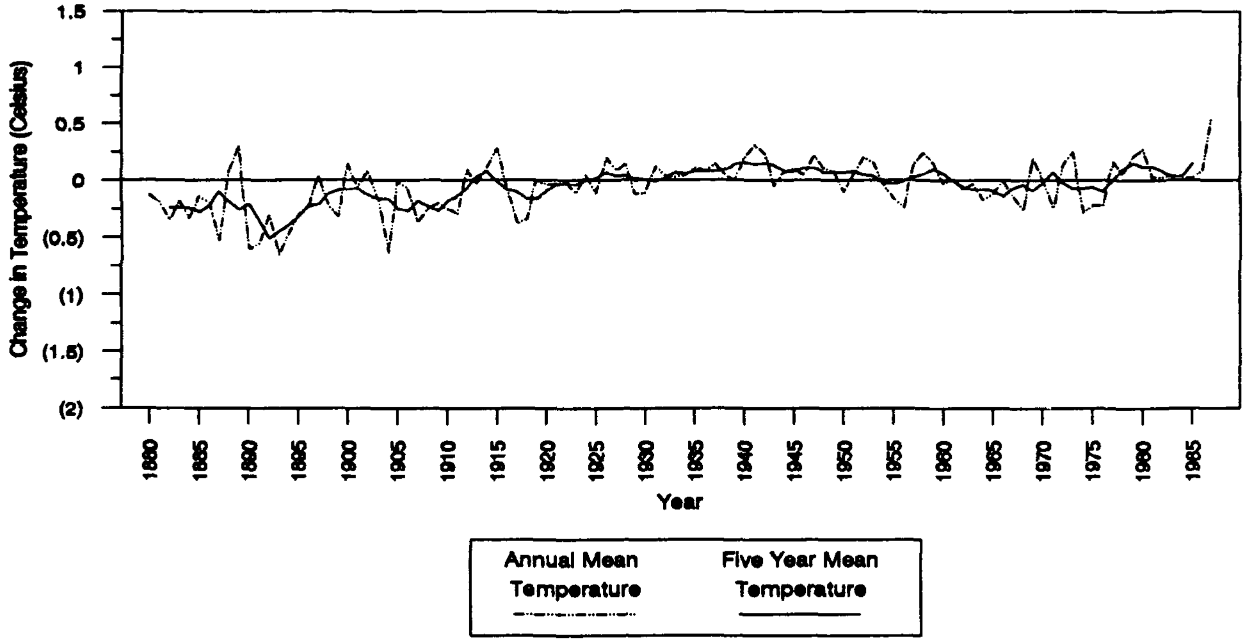
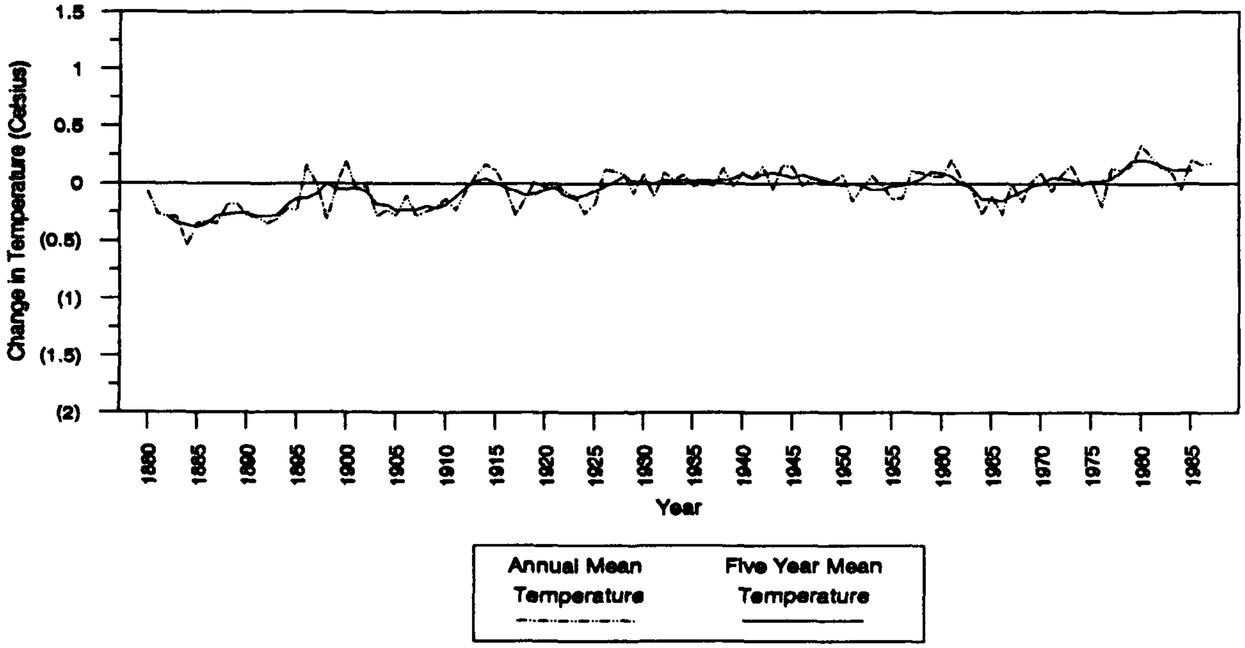



Figure 10: The 64N to 90Nsurface air temperature change




(Hansen and Lebedeff 1987, 1988)

Figure 11: The equator to 24S surface air temperature change




(Hansen and Lebedeff 1987, 1988)

Figure 12: The 24S to 44S surface air temperature change

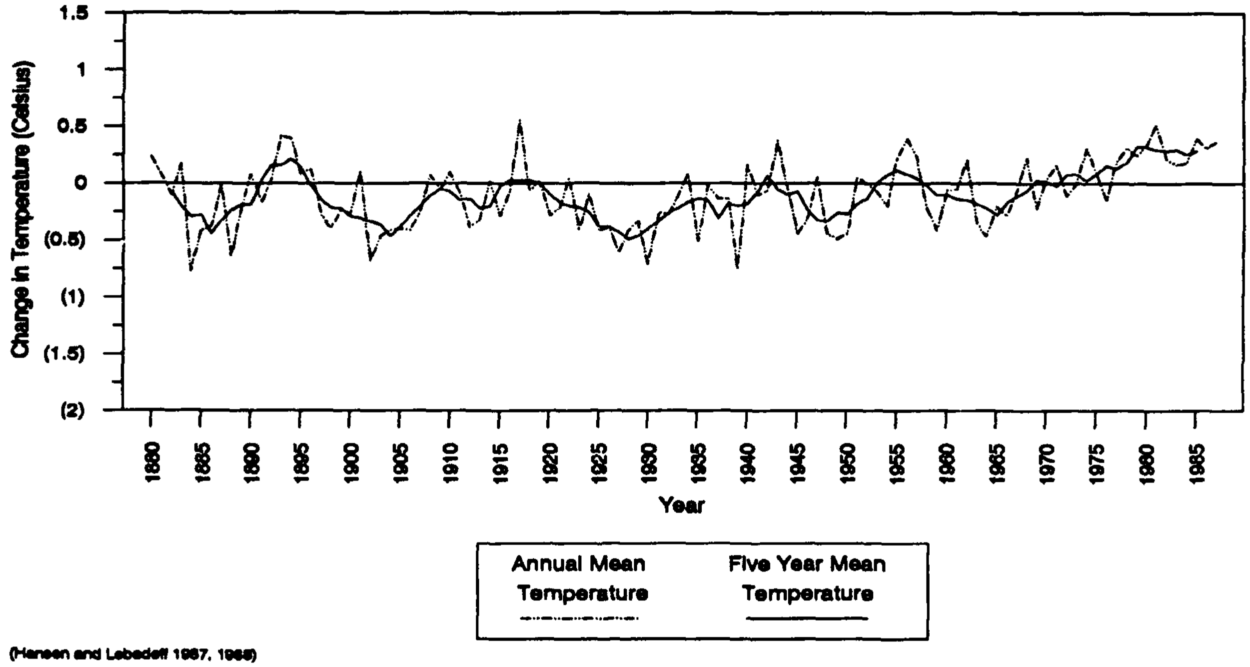



Figure 13: The 44S to 64S surface air temperature change

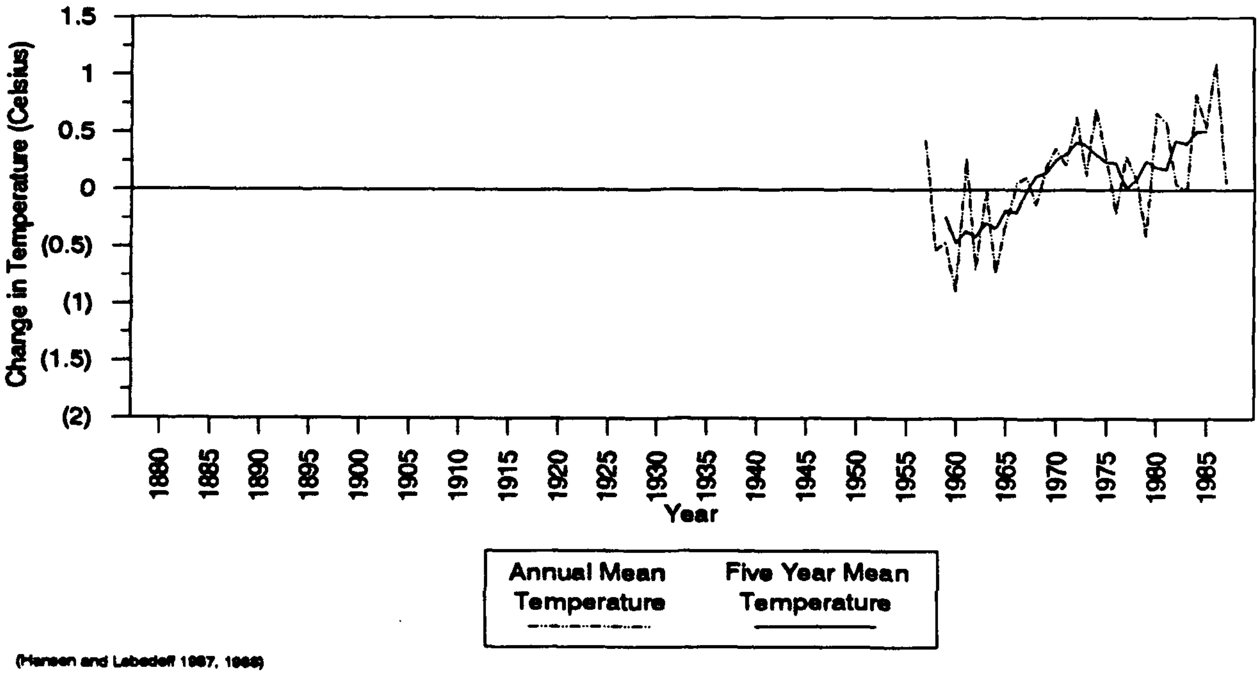



Figure 14: The 64S to 90S surface air temperature change

Undaunted, Hansen provided testimony on June 1988 to the Senate Energy Committee. He stated that with 99% confidence the earth was getting warmer, that with a high degree of confidence the warming was due to the greenhouse effect, and that the U.S. would have to endure a noticeable increase in the frequency of droughts [3-7]. These statements were based on several factors, such as 1988 being unusually warm, and several of the warmest years on record occurring in the 1980's. Most recently Hansen, who strongly believes that we are in a greenhouse warming scenario, bet anyone that one of the first three years in the 1990's would be the warmest on record. He was right. Hansen's land surface data base showed that the global average temperature for 1990 was .45$^{o}$C warmer than normal (the normal temperature is based on the global average temperature from 1951 through 1980.) Yet many other scientists still hold that the temperature increase so far is no greater than the natural variability in average global temperature from year-to-year or decade-to-decade [3-8].

Solow and Broadus [3-9] challenged Hansen's view that the greenhouse effect was the reason for the warming in the 1980's. In their paper, they provided analytical reasoning why the temperature record alone could not explain or demonstrate the existence of an intensified greenhouse effect. In their analysis of the data treated by Hansen and Lebedeff, they found that the average temperature for 1987 was well within the range of natural variability exhibited by the temperature series prior to 1987. In addition, they showed that for any consecutive 8-year period over the past 100 years, the number of warmest years on record during the 1980's was not any more extreme than during the early 1920's and late 1930's.

Richard Lindzen pointed out in a recent article [3-10] that, while temperature was reportedly cooling during 1940 to 1965, the world's industrial revolution was in full swing. Great quantities of greenhouse gasses were being injected into the atmosphere, but there was no corresponding change in the temperature record that reflected an enhanced greenhouse effect.

Spencer and Christy conducted a study on 10 years of satellite data [3-11]. They had determined that there was no warming trend evident from the 1979-1988 period. Unfortunately, the press picked up on this article and declared that scientists found no evidence of global warming.

Nevertheless, Jones and Wigley [3-12] rebutted the findings of Spencer and Christy, and pointed out several serious flaws with the study. Part of the problem was that this study covered a 10-year period. Jones and others had conducted global surface temperature studies similar to the one done by Hansen and Lebedeff, but with a data set that included over water observations. He had no disagreement with the finding that the past 10 years showed no statistical significant increase in global temperature increase. However, Jones argued that the 1980's become the warmest decade on record (being 0.2$^{o}$C warmer than the 1950-1979 average), when viewed over a long period, . Spencer and Christy attempted to show how satellite microwave radiometers should become the standard for monitoring global temperatures. Jones and Wigley took issue. Jones and Wigley stressed that satellites should complement, not replace, ground-based data. Ground-based data measure what is happening on the surface of the Earth, whereas satellites have a difficult time performing such tasks when clouds are present. The thicker the cloud, the less likely that the satellites sensors will be able to detect and measure surface features such as temperature and moisture.

Other factors may be masking the signal that is being sought in the Hansen and Lebedeff temperature time series to show that the greenhouse effect is intensifying. Variations in the amount of cloudiness that covers the Earth's surface may have influenced this masking of the greenhouse effect. Other processes that act upon the Earth's climate system, such as the thermal properties of the oceans or volcanic activity, may have also worked against a rising temperature trend.

# A Regional Temperature Series

There are other interesting changes in the temperature time series on the regional scale which may provide insight into the problem of identifying the signal of an enhanced greenhouse effect. The National Climatic Data Center (NCDC) in Asheville, N.C., has done a regional analysis for the 48 contiguous states. They put together a time series of regional and national averages of maximum, minimum and average temperature, and diurnal temperature ranges across the U.S. for a period from 1901-1987 [3- 13].

The data used is called the Historical Climatology Network (HCN) and consists of 1,219 stations. The HCN is maintained at the NCDC. The spatial density of stations is similar to that used by Hansen and Lebedeff in that there are more reporting stations in the Eastern U.S. than in the Western U.S. A copy of their results is shown in figures 15 through 18. Each figure illustrates the area represented by the data, and includes four graphs which show the maximum temperature, minimum temperature, average temperature, and temperature range (or diurnal temperature). The scale on the bottom of each graph show the years 1895 to 1985 in ten year increments. The scale on the left side of each graph shows the standardized departures (Z), which are defined as:

$$Z=(t-T)/s$$

where:

t = mean annual temperature

T = mean temperature for all years

s = standard deviation of t

Temperatures that correspond to the mean (Z=0) and one standard deviation from the mean (Z=+/-1.282) are given on the right-hand side of each graph, along with the absolute maximum and absolute minimum values for the time series. The smoothed curve is a 9-point binomial filter to serve as a visual aid to identify multi-year climate fluctuations.

The national scale shown in figure 15 shows a dramatic departure from the global averaged temperature change in Hansen and Lebedeff's study. The U.S. had near normal to below normal twentieth century temperatures from 1955 until the 1980's. Thereafter the temperature change increased, but it did not exceed the temperature change for the early 1930's, as did the global and Northern Hemispheric data from the earlier study. The maximum weighted temperature mimicked the weighted average temperature. However, the weighted minimum temperature showed a dramatic rise after 1975, while the diurnal variation (or areally weighted temperature range) decreased.

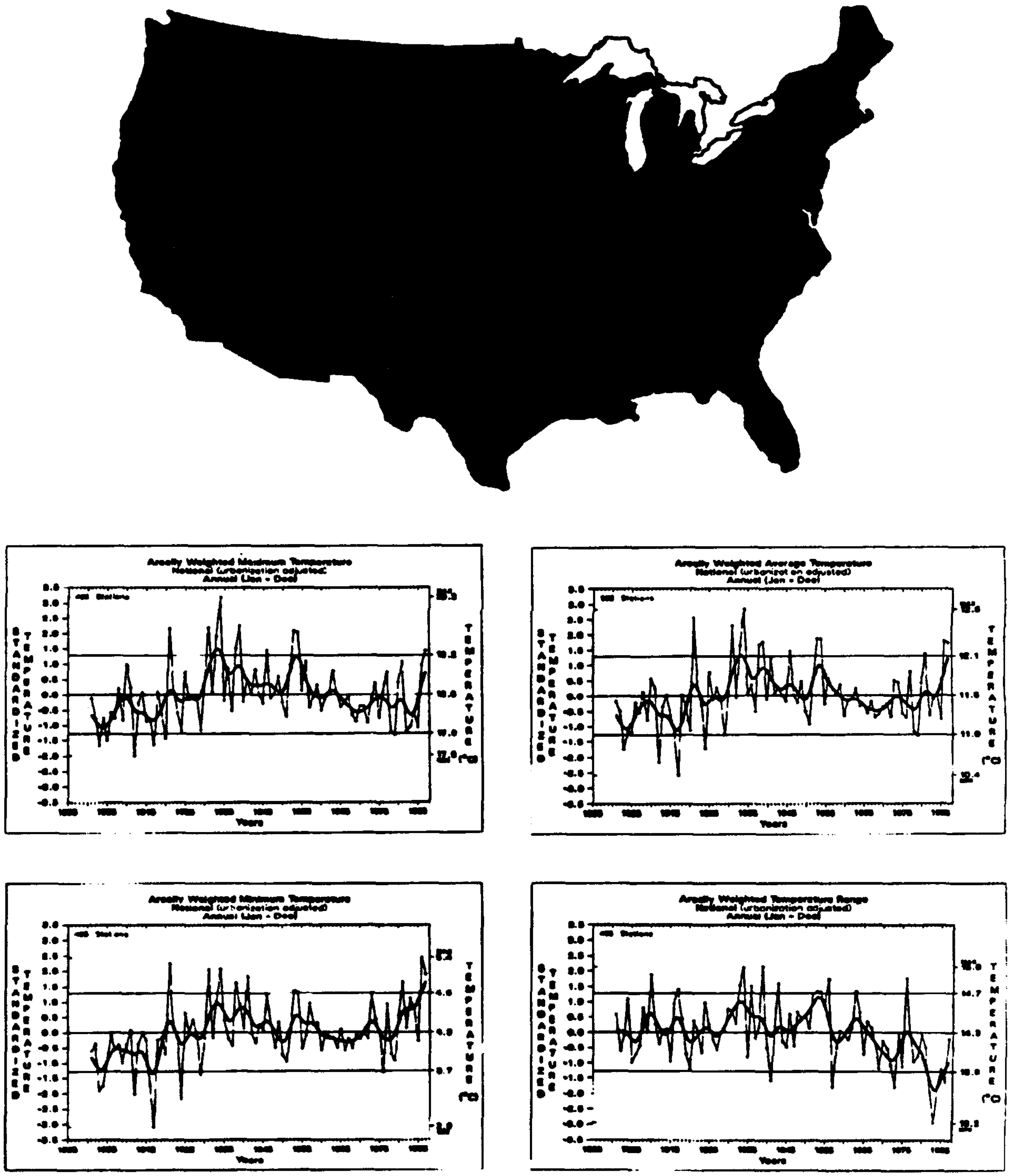
The Western region shown in figure 16 had its average temperature oscillate about the twentieth century mean, but with warmer temperatures in the 1980's. The maximum temperature likewise undulated about the mean, but with no definite warming in the 1980's. The largest changes again occurred with above normal levels in minimum temperature, and a resultant decrease in diurnal temperature variation (or temperature range).

The picture for the Central region, figure 17, appears much the same as the Western region. Average and maximum temperatures oscillated about their means, while there was an increase in minimum temperature and a declining trend in diurnal temperature variation.

The Eastern U.S., unlike the other regions or the national average, had temperatures below the twentieth century average in the 1960's, 1970's, and the first half of the 1980's, as shown in figure 18. The same is true for maximum temperature. The minimum temperature generally remained below average for the region after 1960, but tended to rise after 1980. The diurnal temperature profile showed a tendency toward declining temperatures.

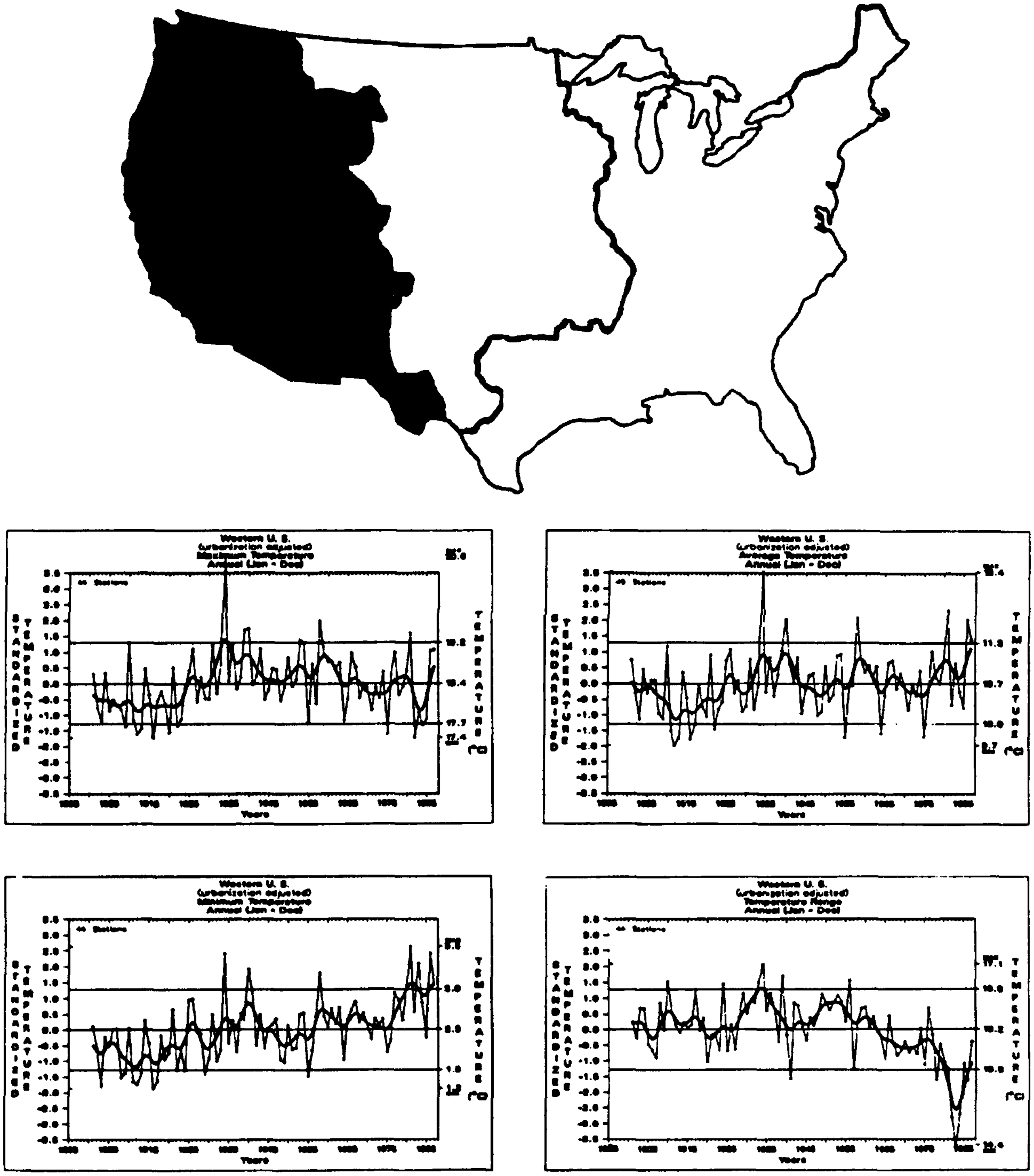
The most consistent pattern in these regional temperature series is the apparent decline in diurnal temperature, and the rise of minimum temperature. Dr. Patrick Michaels, of the University of Virginia, gave a presentation at the 1990 Southeast Regional Climate Symposium [3-14] on this observation. He asserted that the temperature series for the Southeastern U.S. shows increasing minimum temperatures (nighttime temperatures), and a resultant decrease in diurnal temperature in response to increased cloudiness at night. Water vapor that has condensed to form dense cloud layers is an excellent greenhouse gas. Longwave radiation emitted by the Earth's surface, below a layer of dense clouds, is prevented from escaping into space. The net result is a build-up of heat between the cloud's base and the land. This scenario for the Southeastern U.S. is similar to occurrences in other regions in the U.S.

Our present practices of polluting the air, in particular increasing the concentration of sulfates, may be masking the greenhouse signal everyone has been looking for [3-15]. Clouds are an important factor in regulating the world's climate. They trap heat between the cloud's base and Earth's surface, while also reflecting incoming solar radiation back into space. Though sulfates are responsible for acid rain, they do act as excellent hygroscopic nuclei to which water molecules attach and form clouds.



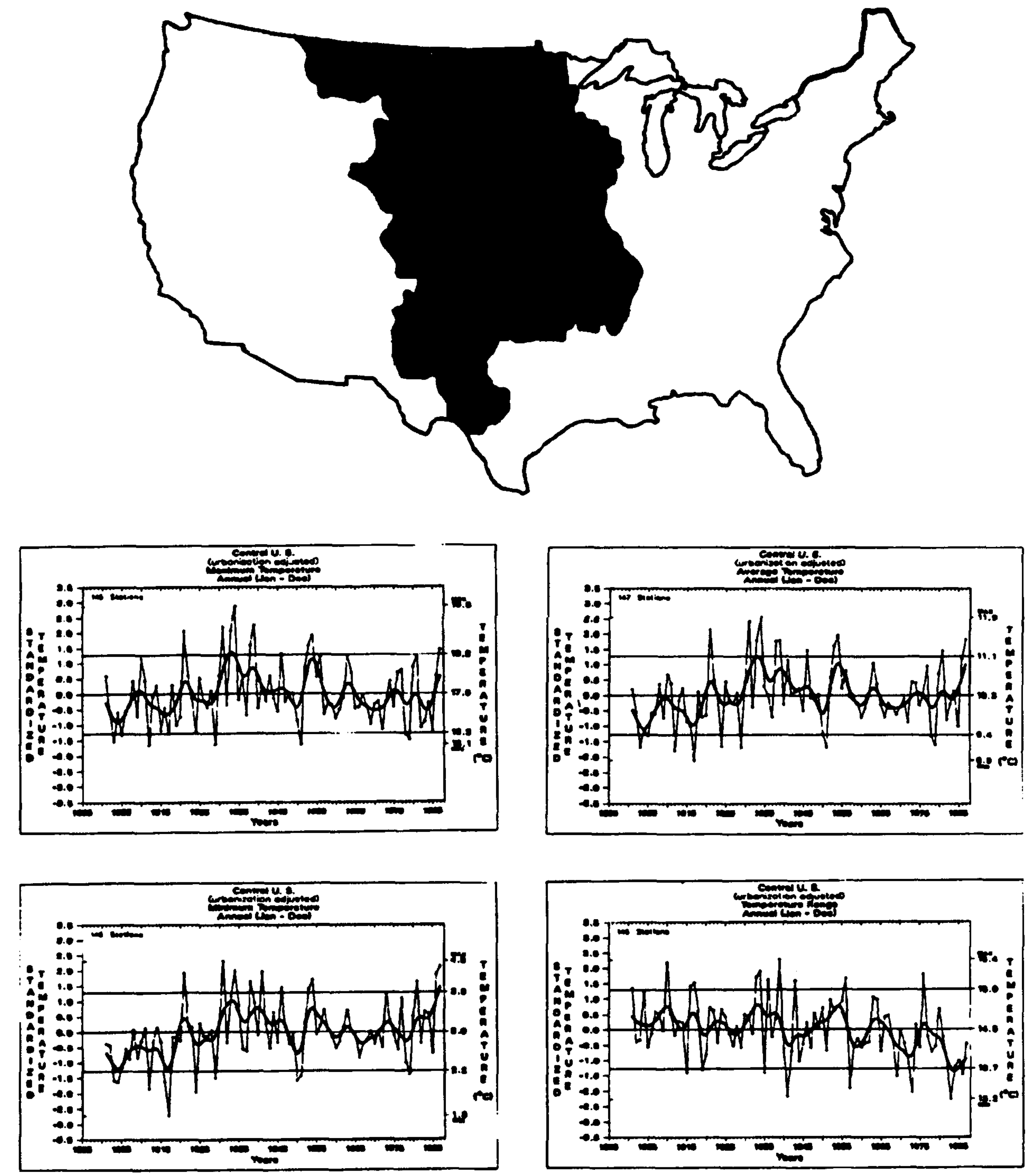
(Source: Karl, Baldwin, and Burgin, October 1989)

Figure 15: Regional temperature series , National mean temperatures.



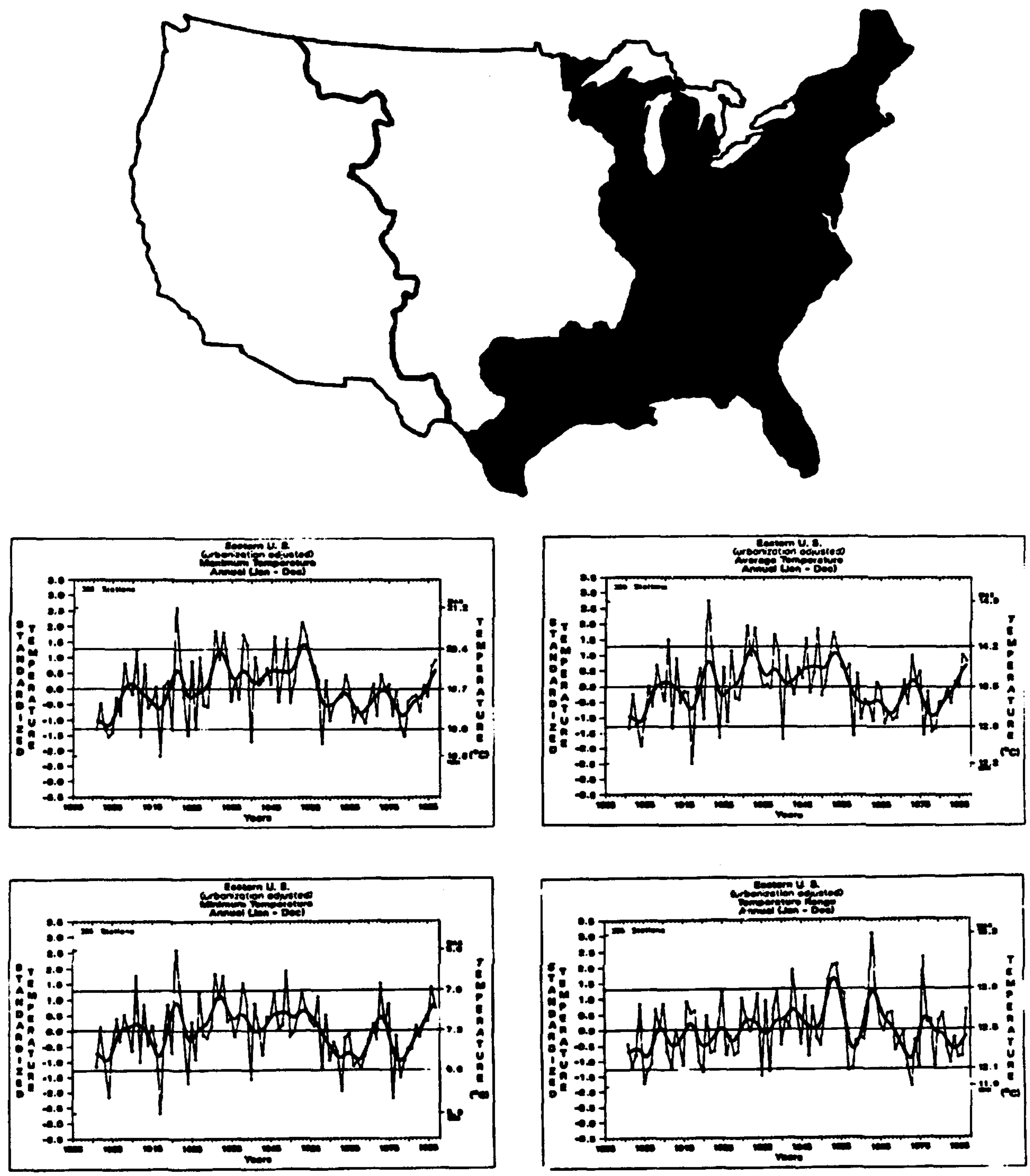
(Source: Karl, Baldwin, and Burgin, October 1989)

Figure 16: Regional temperature series , Western U.S. mean temperatures.



(Source: Karl, Baldwin, and Burgin, October 1989)

Figure 17: Regional temperature series , Central U.S. mean temperatures.



(Source: Karl, Baldwin, and Burgin, October 1989)

Figure 18: Regional temperature series , Eastern U.S. mean temperatures.

Controlling high-sulfur emissions to solve the problem of acid rain may intensify the greenhouse effect by reducing present cloud coverage and the amount of radiation being reflected back into space.

A study by NASA and university scientists provided insight on how pollution was adding to the formation of clouds [3-16] by studying the emissions of vessels at sea. Vessels that burn fossil fuels expel various gasses and particulate matter into the atmosphere. These particles then become the nuclei onto which water molecules attach to form clouds. These clouds, however, are unique among naturally occurring clouds. There are more hygroscopic nuclei present in the polluted area that compete for liquid water in the cloud. This causes the clouds to have more water droplets that are smaller in size than their naturally occurring counter parts. The clouds formed as a result of vessel emissions are then able to have longer life spans as these smaller droplets suppress precipitation, thereby reflecting more solar radiation back out to space. The net result is a prolonged cooling effect.

# A Profile of the Atmosphere

Other evidence that would show an increasing greenhouse effect and a global climate change, is the cooling of the upper atmosphere as a result of increased amounts of greenhouse gasses in the atmosphere. Roble and Dickinson of NCAR reported on expected changes from a doubling of carbon dioxide ($CO_2$) and methane ($CH_4$) on the upper atmosphere [3-17]. The mesosphere (approximately 50-90KM) is expected to cool by 10°C, and the thermosphere (approximately 90-500KM) should cool by 50°C. The stratosphere (approximately 12-50KM) is also expected to cool. A pictorial representation of the atmospheres standard vertical profile is shown in appendix A. This representation shows the major divisions in the atmosphere, the typical height of the different divisions, and their temperature with height. With the number of $CO_2$ molecules increasing, more heat energy will be reflected into space, and potentially cause a greater amount of ozone destruction. A positive benefit is that with a colder upper atmosphere, satellites will be able to remain in orbit longer than at present. As the upper atmosphere cools, its height above Earth's surface would decrease. Therefore a satellite would be less likely to encounter the top of the atmosphere and lose its orbit if the upper atmosphere was lowered.

Karoly of Monash University in Melbourne, Australia, examined upper air temperatures measured by balloons at 147 stations in the Northern Hemisphere from 1964 to 1985 [3-18]. The results of his study showed that there was a statistically significant pattern of divergence between tropospheric and stratospheric temperatures. Unfortunately, the record for the upper atmosphere is more limited than that for the surface. The number of upper air observing stations are fewer in number than surface observing posts. Also, equipment for upper air observations fail from time to time that result in a loss of observations. With the increased interest in global climate change internationally, and an enhanced space program that will monitor global climate, many gaps in the present network will be more than adequately filled.

Whether the "greenhouse effect" is really intensifying or not is still a matter of considerable debate. The temperature record is admittedly vague, but the likelihood of encountering significant and rapid temperature increases cannot be ignored. The potential for warming, and the intensification of the greenhouse effect, is increasing because of the quantity of gasses being injected into the atmosphere that contribute to this effect.

# THE SECULAR RECORD OF GREENHOUSE GASSES AND OTHER TRACE GASSES

A great concern about global climate change has been the injection of greenhouse gasses into the atmosphere. The increased concentration of these gasses could lead to a warming of Earth's climate, and unwanted changes in other segments in the Earth system. Another reason for the increased concern is the realization that human activities have had a deleterious effect on segments in the Earth system. The effects have occurred on a global scale. The hole in the ozone layer is the prime example of that effect. The hole is now the size of Antarctica during the Southern Hemisphere's summer months, and it appears to be growing. The damage to the ozone layer is attributable directly to the use of chlorofluorocarbons (CFC's) over a long period. These gasses are man-made, and are not naturally occurring. Besides ozone destruction, CFC's directly contribute to Earth's warming climate, or the *greenhouse effect.* Unfortunately CFC's have a very long residence time in the atmosphere, almost a century long. What other change in the Earth system can be anticipated from humanities past and present attempt to exploit and manage Earth's resources?

Climate is a sensitive component in the Earth system, and can react radically to changes in other segments in the Earth system. For example, the geologic record shows an apparent relationship between Earth's average temperature to changes in the concentration of $CO_2$, and methane ($CH_4$). This has caused many people to become concerned about the amount of greenhouse gasses being added to the environment. The concerns have centered on how these chemicals will affect the climate and environmental subsystems in the Earth system, and the rate at which changes will occur. These gasses are being introduced into the atmosphere in large quantities. Approximately 5.6 billion tons of $CO_2$ are being injected into the atmosphere annually by the U.S., which accounts for over 20% of the world's total emission rate [4-1]. It is unlikely that the present trend of burning fossil fuels (the major source of $CO_2$) for energy and the release of untreated exhaust gasses into the air will diminish in the near future. The world's main energy source is carbon-based. Therefore, it is not an easy matter to impose a curtailment of the release of $CO_2$ to a predetermined amount. There are significant socioeconomic considerations that must be considered before any amount of worldwide cooperation can be expected.

$CO_2$ is not the only important atmospheric gas that is forcing changes to the climate system. Table 1 lists 16 gasses that have either a direct or indirect impact on the

Table 1: Greenhouse gasses and other trace gasses.

| Trace Gas | Chemical Name | Average Life in the Atmosphere | Sources | Current Concentration (ppmv, circa 1985) | Trend per Year | Radiatively/ | Chemically Interactive |
|---|---|---|---|---|---|---|---|
| $CO_2$ | CARBON DIOXIDE | 7 Years | Fossil fuels | 345 | 0.4% | Y | N |
| $O_3$ | OZONE | Hours-Days (trop.)<br>Hours-Months (strat.) | Troposphere-photochemical and transport from stratosphere<br>Stratosphere-photochemical processes | Trop. 0.02-0.1<br>Strat. 0.1-10 | increasing<br>decreasing | Y<br>Y | Y<br>Y |
| $CH_4$ | METHANE | 11 Years | Biogenic activity, and fossil fuels | 1.6-1.7 | 1.0%-1.2% | Y | Y |
| CO | CARBON MONOXIDE | .4 Years | Biogenic activity, and motor vehicles | N.Hemisphere 0.2<br>S.Hemisphere 0.05 | 1%-5% | N | Y |
| $N_2O$ | NITROUS OXIDE | 150 Years | Fossil fuels | 0.31 | 0.2%-0.3% | Y | Y |
| $NO_X$ | REACTIVE ODD-NITROGEN | 1-7 Days (trop.)<br>>7 Days (strat.) | Stratospheric oxidation of nitrous oxide, lightning, soils, oceans, fossil fuels/biomass combustion, and jet aircraft | 0-0.02 | — | Y | Y |
| OH | HYDROXYL | Seconds-Minutes | Troposphere-by-product of hydrocarbon oxidation<br>Stratosphere-by-product of methane oxidation | $5X10^{-8}$ | — | N | Y |
| $CFCL_3$ | TRICHLORO-FLUORO METHANE (CFC-11) | 75 Years | Refrigerant/AC, plastic foams, and aerosols | $2X10^{-4}$ | ~5% | Y | Y |
| $CF_2CL_2$ | DICHLORO-DIFLUORO METHANE (CFC-12) | 110 Years | Refrigerant/AC, plastic foams, and sterilants | $3.2X10^{-4}$ | ~5% | Y | Y |
| $CF_2CLBR$ | BROMO-CHLORO-DIFLUORO METHANE (Ha-1211) | 25 Years | Fire extinguisher | $1X10^{-6}$ | 10%-30% | ? | Y |
| $CF_3BR$ | BROMO-TRIFLUORO METHANE (Ha-1301) | 110 Years | Fire extinguisher | $1X10^{-6}$ | — | Y | Y |
| $SO_2$ | SULFUR DIOXIDE | 5 Days | Volcanoes, coal and petroleum burning, smelting of ores | $1X10^{-5}$ - $20X10^{-5}$ | — | Y | Y |
| COS | CARBONYL SULFIDE | 2-2.5 Years | Oceans, soils, volcanoes, marshes, biomass burning, coal-fixed power plants, and motor vehicles | $5X10^{-4}$ | <3% | Y | Y |
| $CH_3CCL_3$ | METHYL CHLOROFORM | 8 Years | Industrial & natural processes | | | | |
| $CCL_4$ | CARBON TETRACHLORIDE | 67 Years | Industrial processes | | | | |
| $C_2F_3CL_3$ | CFC-113 | 90 Years | Solvents | | | | |

(Sources: Wuebbles and Edmonds, 1988, and Jutro, Worrest, and Janetos, 1989)

Earth system, and in particular global climate change. The table lists their chemical formula, name, average life span in the atmosphere, their sources, current concentration, present trends in their concentration (either increasing or decreasing), and whether they are radiatively or chemically interactive. Each of the gasses contributes to the global climate change process in varying degrees. Studies on greenhouse gasses were conducted by the United States Department of Energy [4-2] and the Environmental Protection Agency [4-3]. Their work is used extensively in the following summary of each gas.

$CO_2$ is the most abundant greenhouse gas in the atmosphere. It affects Earth's average surface temperature and contributes to the ozone depletion process. The greenhouse theory says in part that with global warming in the troposphere, cooling will occur in the stratosphere and other higher layers in the atmosphere. Since ozone depletion in the stratosphere depends on extreme cold temperatures and sunlight [4-4], $CO_2$ would worsen the destruction of this critical layer to Earth's biosphere.

Figure 19 shows the mean monthly concentration of $CO_2$ that has been observed at the Mauna Loa Observatory, Hawaii [4-5]. This gas has had steady growth since the beginning of the Industrial Revolution. There is no indication that this growth rate will be either stopped or slowed. The effect of the biosphere on the concentration of $CO_2$ in the northern hemisphere is evident by the sawtooth appearance of this graph. In the fall there is an escalation in $CO_2$ concentration due to all the leaves and other

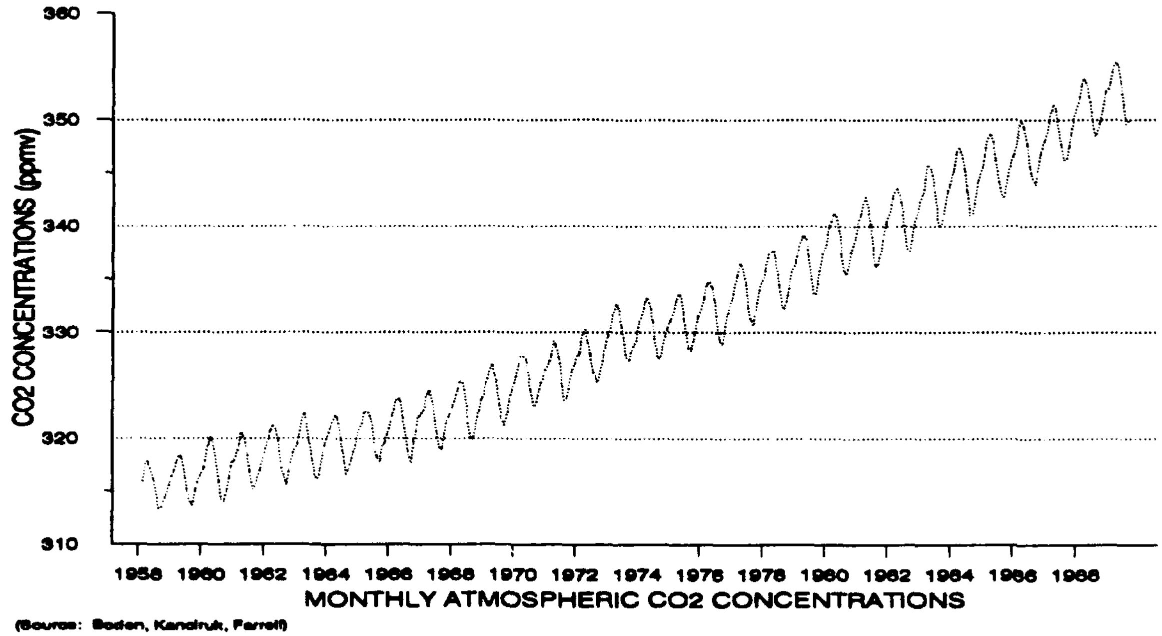



Figure 19: Approximate mean monthly concentrations of $CO_2$ at Mauna Loa.

biomass that has fallen and decomposed. In spring the atmospheric concentration of $CO_2$ falls as new plant growth absorbs this gas.

Ozone ($O_3$) is a potent greenhouse gas as well as an extremely important agent in screening ultraviolet radiation (UVB). It exists in the troposphere and the stratosphere. In the stratosphere it acts to reflect solar radiation, but in the troposphere it traps the infrared radiation emitted by Earth, preventing it from escaping into space. If there were either a reduction of stratospheric $O_3$ or an increase in tropospheric $O_3$, then surface temperatures would be expected to rise.

It has not yet been determined if changes in $O_3$ concentrations in the upper and lower atmosphere will affect the overall incidence of UVB radiation at the Earth's surface. Yet, if UVB was to penetrate to the Earth's surface, it could have a profound and adverse influence on the biosphere and human activities, and could amplify its influence on climate change.

Methane ($CH_4$) is a more powerful greenhouse gas than $CO_2$. Its impact on the world's climate is fortunately minimized by its low atmospheric concentration. The potential for a sudden increase for this gas in the atmosphere is great. Vast quantities of $CH_4$ are contained in bogs, wetlands, and the arctic tundra. If temperature increases cause these areas to dry, then there could be an accelerated release of this gas into the atmosphere.

Ruminate, or cud-chewing, animals (such as cattle, sheep, goats, buffalo, and camels) also contribute to the general increase of this gas in the atmosphere. Their numbers have increased in recent years, making them a significant contributor to this problem. This is correctable by adjusting their diet through improved feed and nutrition. The use of hormones with improved nutrition could increase the animal's productivity, reducing the number of livestock on a farm [4-6].

$CH_4$ is a major contributor to the production of tropospheric ozone (another greenhouse gas), and to the destruction of stratospheric ozone. $CH_4$ is an important source of stratospheric water vapor ($H_2O$) that is another effective greenhouse gas and contributor to the destruction of stratospheric ozone.

Carbon monoxide (CO) is not an important radiative gas by itself. Still, it does contribute to the greenhouse effect and to ozone depletion by reacting with other trace gases. It directly influences the amount of $CH_4$ in the atmosphere and $O_3$ in the troposphere.

Nitrous oxide ($N_2O$) has strong radiative properties that make it an effective greenhouse gas. Its average life in the atmosphere is the longest of any other of the trace gases, but as with methane, its low concentration in the atmosphere prevents it from being a major factor now in global climate change. This gas has an indirect but significant role in the destruction of the ozone layer. $N_2O$ is a major source of the reactive odd-nitrogen ($NO_x$) in the stratosphere.

The reactive odd-nitrogen ($NO_x$) is an effective absorber of infrared radiation. But, it has nominal direct impact on Earth's warming due to its low concentration level relative to other green house gasses. It does have major, though indirect, impact on the Earth system. $NO_x$ destroys stratospheric ozone, and contributes to the creation of ozone in the troposphere.

The hydroxyl (OH) is a byproduct of the hydrocarbon oxidation in the presence of $NO_x$ in the troposphere and with $CH_4$ in the stratosphere. Its average life span in the atmosphere is the shortest of any of the 16 trace gasses, and it lacks radiative properties that relate directly to climate change. Indirectly, it has a strong effect on other radiative gasses such as $CH_4$ and CO. It contributes also to the stratospheric ozone destruction, and initiates tropospheric photochemical smog production.

Chlorofluorocarbons (CFC-11, CFC-12, CFC-113) contribute to both the greenhouse effect and ozone depletion. Their effect on the ozone layer and the greenhouse effect are compounded by long average life spans in the atmosphere. They are not a naturally occurring gas, but are man-made. As a result, the potential to limit and ultimately remove these chemical compounds from the atmosphere is good. Several countries have signed the Montreal Protocol that set in place a mechanism to regulate the use and manufacture of CFC's.

CFC's are not only effective greenhouse gasses, but they are the primary sources of chlorine (Cl) in the stratosphere. Cl is a highly efficient destroyer of $O_3$ in the presence of sunlight in extreme cold conditions.

Brominated halocarbons (Ha-1211 and Ha-1301) share similar traits with CFC's. They are both manufactured, and are not naturally occurring substances. They also contribute to the destruction of ozone. Ha-1301 is only known to be an absorber of infrared radiation. The radiative properties of Ha-1211 are not well known at this time.

Sulfur dioxide ($SO_2$) is another trace gas that is an effective infrared absorber, but it is a nominal contributor to the greenhouse effect due to its very low atmospheric concentration.

Carbonyl sulfide (COS) is a very minor gas in terms of general change in the world's climate. Its effect in stratospheric ozone destruction is again indirect as it reacts with other trace gasses to cause the adverse conditions in the ozone layer.

Methyl chloroform ($CH_3CCL_3$) and carbon tetrachloride ($CCL_4$) are both effective greenhouse gasses and contribute either directly or indirectly to the destruction of ozone in the atmosphere.

The interactions among the above trace gasses in the atmosphere are complex, but their contribution to the greenhouse effect and ozone destruction are well documented. The atmosphere can no longer be considered an infinite sink for dumping chemicals without having to consider the consequences of such acts. The destruction of the ozone layer is a testament to the scope of the problem we face from the continued release of these gasses into the atmosphere. Adverse changes can suddenly appear, and our ability to analyze and respond to these changes may be ineffectual in the near term.

# RECENT RESEARCH EFFORTS ON CLIMATE CHANGE

There are several factors that have impact on the world's climate system such as the varying levels in atmospheric concentrations of carbon dioxide ($CO_2$)and methane gasses. Their influences in the geologic past on the world's temperature can be seen in ice core records. The influence of other factors such as clouds and the ocean is still uncertain. The world's glaciers and snow packs, clouds, forests, oceans, and volcanoes have been studied recently to determine their impact on the magnitude and direction of global climate change (GCC).

## The Oceans and Plankton

Probably the most significant events that alter periodically climate on a worldwide scale are the El Nino and the Southern Oscillation (ENSO) events. These two events are tied to one another and occur every two to seven years. There is a linking between the ENSO event and dramatic changes in the weather patterns over practically every continent and ocean basin in the world.

First identified by 19th century Peruvian fishermen, El Nino was considered to be a singular and periodic event that affected the west coast of South America [5-1]. Typically cold, nutrient-rich water upwells off the Peruvian coast, and the area teems with marine life. During an El Nino event, the upwelling of the nutrient-rich water is disrupted, surface waters warm, and there is a dramatic fall in marine life.

The Southern Oscillation event was first identified in 1920. This event is characterized by the periodic displacement of typical pressure and precipitation patterns across the Indian Ocean and tropical Pacific. Normally, high pressure resides over the eastern Pacific, and low pressure over Australia, the Indian Ocean, and Africa. Similarly, greater amounts of rainfall are associated with the low pressure areas than with areas of high pressure. The Southern Oscillation event occurs with the same regularity in time as El Nino, but its duration is a few months longer. When this change sets in, there is a significant decrease in rainfall and higher surface pressure in the western Pacific and Indian Ocean areas. In the eastern Pacific there are generally greater amounts of precipitation, and lower surface pressure than normal.

The Southern Oscillation Index (SOI) was developed to monitor and crudely predict the occurrence of southern oscillation events. It was found that the onset of the Southern Oscillation could be determined by measuring the sea-level pressure anomaly between Tahiti and Darwin, Australia. Positive values of the SOI denote the strengthening of the climatological mean pressure gradient that increases the easterly winds over the tropical region. A decrease in the SOI is indicative of warmer and drier conditions. The warming causes a more homogeneous sea surface temperature, which further weakens the easterly trade winds. Warm events usually reach a maximum six months after they begin, followed by cold events of near equal intensity a year later [5-2], called La Nina.

La Nina is the antithesis of El Nino in that the equatorial central and eastern Pacific experience below normal sea surface temperatures. The large-scale Pacific tropical convective zone is also near its climatological mean position. La Nina is not a complete opposite of El Nino, in that the magnitude of change in the ocean's surface temperatures do not reach the level attained during El Nino. Further, the influence of an El Nino and Southern Oscillation event on the atmosphere is strong, whereas there is no physical process that allows a La Nina event to influence atmospheric events directly [5-3].

By 1957 it became apparent that the El Nino and Southern Oscillation events were related, and that the El Nino was a manifestation of atmospheric and oceanic interactions. The discovery of the link between El Nino and Southern Oscillation provided more insight on how this process operates and the possible impact a changing environment would have on the biosphere.

It is now known that the following conditions in the tropical regions normally precede an ENSO episode by a few months [5-4]:

- A slackening of the Pacific trade-wind system with westerlies first appearing in the western Pacific.
- A rise in pressure in the western Pacific, and a drop in pressure in the central and eastern Pacific.
- Above normal sea surface temperatures in the eastern Pacific that persist beyond normal wintertime annual warming.
- A rise in sea surface temperatures in the central Pacific from warm water advected from the western Pacific, and a corresponding increase in convective activity.
- A decrease in sea level in the western Pacific, and a rise in sea level in the eastern Pacific. There is a corresponding decrease in the mixed layer depth and surface heat content in the western Pacific, and an increase in the eastern Pacific.

Richard Barber [5-5] outlined how the oceans changed during an ENSO event. The usual thermal pattern in the tropical Pacific is a deep thermocline (about 200m below the ocean's surface) with heat storage in the western Pacific, and a shallow thermocline (about 50m below the ocean's surface) and low heat storage in the eastern

Pacific. The nutricline lies below the thermocline, and so it is closer to the surface in the eastern Pacific than in the west. The closer the nutricline is to the surface, the closer it is to the depth that light can penetrate and where a host of the biotic activity occurs. The proximity of the nutricline to the ocean's surface has a direct bearing on the enrichment of primary productivity (organic production rates by photosynthesis).

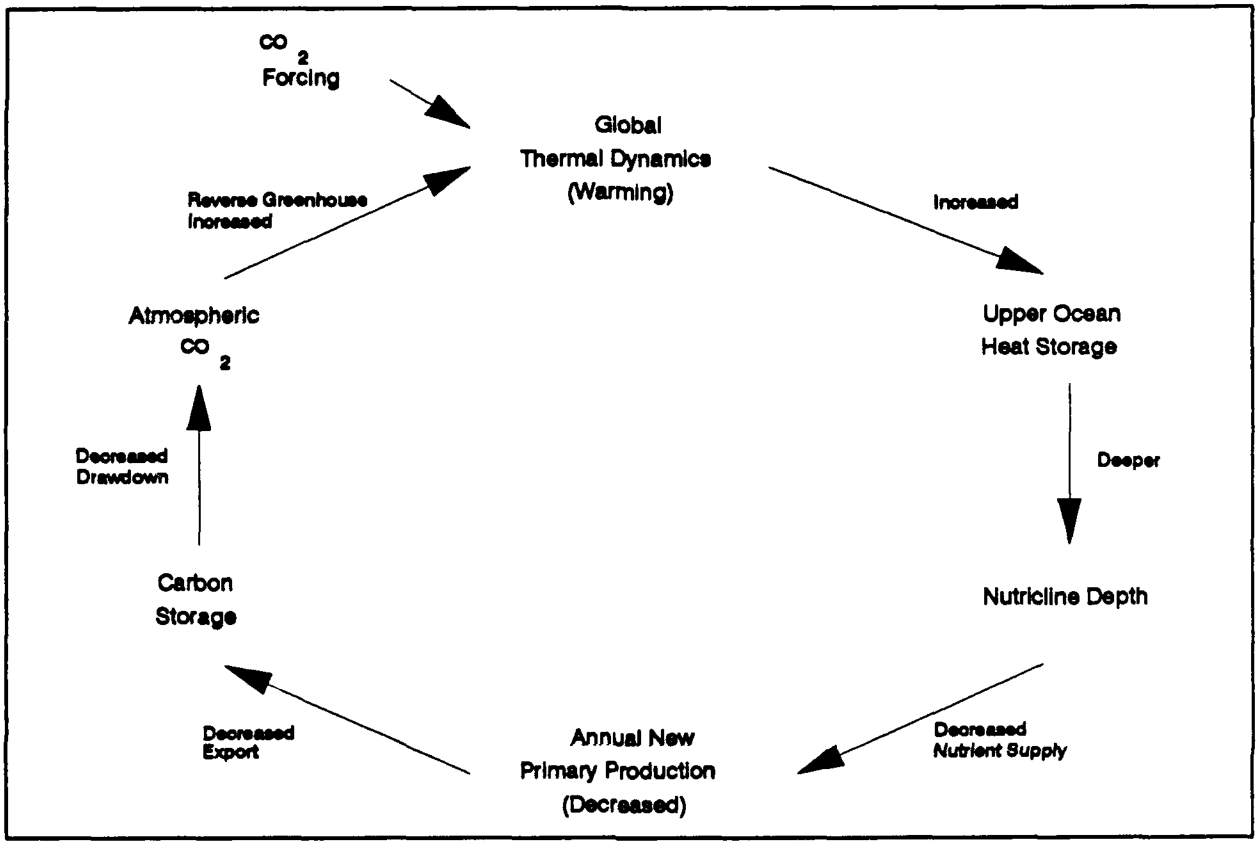
Sea level in the western Pacific, in addition, is 40 cm higher than in the eastern Pacific from wind forcing caused by easterly trade winds. During an ENSO episode, the trade winds abate, and the sea level across the Pacific basin adjusts to become flatter. As a result, warm water above the thermocline in the western Pacific shifts eastward, decreasing the mixed layer above the thermocline and nutricline in the central and western Pacific. The upwelling process in the eastern Pacific is generally cut off, but not always. The important effect, however, is the significant decrease in primary productivity in the eastern Pacific due to an increased heat content in the upper ocean. The source of vital nutrients to support a normal level of biotic activity is well below the depth that light can penetrate, and is unavailable.

A rapid decrease in primary production can indirectly enhance the greenhouse effect due to a decrease in the amount of $CO_2$ uptake by the oceans. Barker reported that there is a direct relationship between the ocean's thermal dynamics and primary productivity. In 1988, a study showed that there was a 40% increase in productivity and an eventual 30% draw-down of atmospheric $CO_2$ with enhanced trade winds that spurred more upwelling. During an ENSO event, and decreased primary productivity in the eastern Pacific, there is an indirect result of increased atmospheric concentrations of $CO_2$. A paradigm of this air/ocean interface and its effect on primary productivity is shown in figure 20. What is lost in the eastern Pacific is gained in the west, though it is not certain whether the increase in primary productivity in the western Pacific compensates for the loss in the eastern Pacific.

There have been many hypotheses about the origins and scale of the ENSO events. It is believed that the ENSO and monsoon system are all part of a global scale phenomenon that operates on an interannual time scale. The observed changes in surface pressure, surface wind, and precipitation are thought to originate in the Indian Ocean, and then propagate eastward. Further, it is thought that substantial anomalous heating in the tropics can modify the general circulation in that region, and lead to the beginning of an ENSO event.

The effects of ENSO are worldwide. Schneider [5-6] reported that results of general circulation models (GCMs) show how tropical ocean temperatures influence the climate of the mid-latitudes. The typical weather pattern over the mid-latitudes is disrupted by the alteration of the jet stream's position and intensity from normal, thereby changing the regions over which warm and cold climates are divided.

The following list provides an overview of how pervasive the ENSO effect is on precipitation patterns [5-7]:




(Source: Adapted from Barber, 1980)

Figure 20: The impact of global warming on the ocean system and the atmosphere.

- Pacific Basin-Increased precipitation in the central Pacific and south central Pacific; decreased precipitation in the western Pacific.
- Australia-Generally dry over most of the continent.
- Indian Subcontinent-Generally dry except in the extreme southern part of India where it is wetter.
- Tropical and Southern Africa-Greater than normal precipitation.
- Northern Africa, Southern Europe, and Middle East-Above normal precipitation.
- South America-Below normal precipitation over northeast South America, and above normal precipitation over southeastern South America.
- Central America and the Caribbean-Mostly dry.

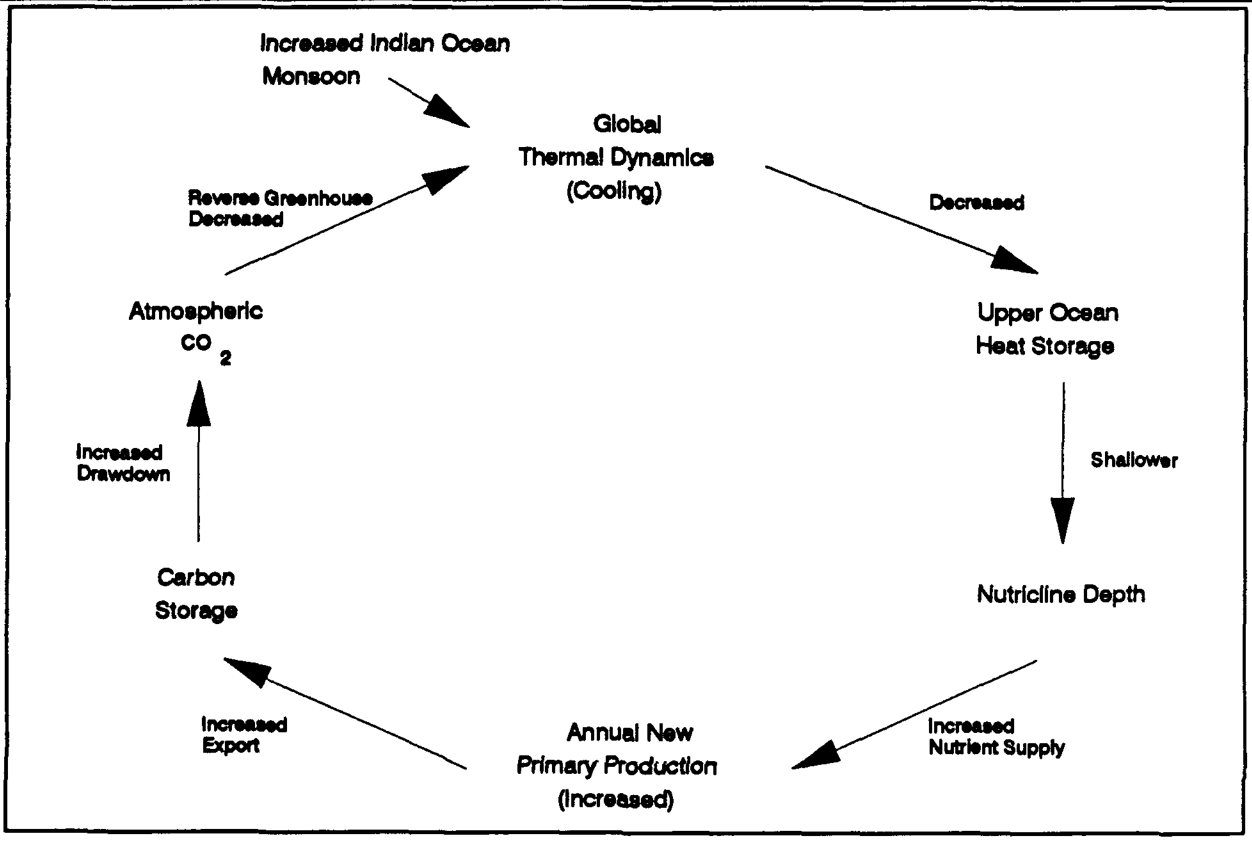
The 1982/1983 ENSO episode was the most intense on record, and its effects were devastating worldwide. The following summary highlights some of its effects across the world [5-8]:

- Coral reef deaths from moss coverings.
- Changes in the species of moss that grew on the Galapagos Islands resulted in a large death toll of reptilian life which could not digest the new moss.
- A disastrous fire season in California occurred the year following a period of greatly increased rain, and a resultant increase in vegetation.
- Drought in Africa.
- Increased hurricane activity in the central Pacific, where landfalls occurred in areas that had no strikes in 50 years.
- IIncreased precipitation in the southeast U.S.

The ENSO event provides some insight into what a changing environment can do on a global scale, but much is still unknown. There is a worldwide effort underway to discover more about this important phenomena. TOGA (Tropical Ocean-Global Atmosphere) is an ongoing 10-year study that is nearly half completed. To this point, the effort has been to install a series of monitoring devices to measure several parameters in the atmosphere and ocean. The goal of this major effort is to investigate the predictability of the coupled tropical climate system, and to establish a predictive capability and an observing system to support it.

The ocean's role in global climate change (GCC) is immense. Not only is there a direct relationship with changing weather patterns due to the ENSO, but it also affects the concentration of atmospheric greenhouse gasses, and influences land/ocean interactions. Bakun [5-9] wrote about the expected global warming and resultant heating of coastal land surfaces. He reported that heat lows would become more intense adjacent to upwelling regions. There would be an increased thermal gradient over the coastal area, intensifying near shore winds, and accelerating coastal upwelling circulations. The study has shown a general increase in wind stress along the California, Iberian Peninsula, Morocco, and Peruvian coasts from 1950 to 1985.

The effect of such changes in the coastal environment may be increased primary productivity of marine life from enhanced upwelling, but the marine industry could encounter difficulties. With increased wind over water surfaces, waves will build and could increase a vessel's steaming time and operating costs, and limit its type and amount of loading. In addition, the frequency of small craft conditions (winds generally greater than 20 kts) may increase, limiting various forms of marine operations, and impacting on U.S. Army beach operations.




(Source: Adapted from Barber, 1990)

Figure 21: The impact of global warming on the ocean system and the atmosphere.

Another area that could influence Earth's climate is the Indian Ocean. It was found that the Indian monsoon may provide a means to increase the draw-down of $CO_2$ from the atmosphere. Strong winds encourage biological activity in the upper ocean above the thermocline by increasing subsurface turbulence. The turbulence forces nutrients in deep water to lift toward the surface where photosynthetic activity occurs. As microorganisms bloom from the increased nutrients, they increase their uptake of $CO_2$, drawing the gas from the atmosphere [5-10]. The process is graphically shown in figure 21. It is similar to that shown in figure 20, but the direction of change is opposite.

The oceans have a significant role in regulating the atmosphere's concentration of $CO_2$. A recent article reported that in a warming environment the oceans will be able to increase the current rate of $CO_2$ uptake. Previously it was believed that the oceans could dissolve $CO_2$ more efficiently in cold temperatures. However, the most recent study reported that, contrary to early thought, more $CO_2$ was absorbed by the oceans in the midst of summer [5-11]. The results were attributed again to photosynthetic activity. With increased surface temperatures there is increased activity by plankton which draws more atmospheric $CO_2$ into the ocean. The warmer temperatures also shut down convective currents in the oceans that would normally advect $CO_2$ rich water from the deep ocean to the surface. Oceanic processes could therefore impede rapid advances in global warming. As Earth warmed, the summer months would lengthen and encourage increased photosynthetic activity, thereby extracting more $CO_2$ from the atmosphere.

It is suspected that plankton can influence climate in another significant way. Slingo reviewed the Gaia hypotheses, and the results of some studies that either refuted or supported it [5-12]. The Gaia hypothesis, or homeostatic Gaia as it is now termed, describes how the biosphere can maintain climate within tolerable limits. A study by Charlson, et al. [5-13], described how plankton indirectly controlled climate through their excretion of dimethylsulphide (DMS). DMS becomes oxidized when exposed in the free atmosphere to form hygroscopic nuclei, or sulfate particles. Water molecules then collect on these nuclei to form clouds over remote ocean areas where other cloud-forming processes are not present. Because clouds have a powerful influence on climate, the role of plankton as a biogeophysical feedback mechanism in GCC would be very important.

A separate study refuted the role of DMS in cloud formation and the contribution of DMS to GCC. This study, by Schwartz [5-14], looked at man-made emissions of sulphur dioxide. Man-made emissions of sulphur dioxide has twice the atmospheric concentration on average globally than that generated by plankton. It was reasoned that if Charlson et al., were correct, then the effects from anthropogenic emissions should be evident. The findings of the study, however, showed that the human influence did not significantly influence climate consistent with what would be expected from the increased emissions of sulphur dioxide. The author reasoned that, as a result, the influence of plankton would be even smaller.

In reviewing this study, Slingo pointed out that the evidence used by the author looked at only the brightness of clouds to determine overall differences in albedo (the ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it), which directly influences GCC. The study neglected to determine the changes overall in the amount of cloudiness, which could have made the findings of this study more substantive.

Later research by Prospero and Savoie countered Schwartz's study. They measured the quantities of biological sources of sulfur compounds in remote oceanic areas and found that there is a considerably higher concentration of sulfate from biogenic sources than from anthropogenic sources over these remote sites [5-15]. When measuring these concentrations at Midway Island, they found biological sulfate to be four times as abundant as continental sulfate.

There is no doubt as to the importance of clouds in controlling climate, but there is still considerable doubt among many scientists as to the significance of plankton's role in the generation of clouds. If the role of plankton is found to be significant in the generation of clouds, then the impact of the hole in the ozone layer will be magnified. For as more UVB radiation penetrates into the lower atmosphere and upper oceans, it could only have adverse effects on the plankton's population. A reduced plankton population will then lead to less DMS, fewer sulfates, and reduced cloudiness to reflect solar radiation. The plausibility of this scenario is yet to be determined.

## Clouds

The advent of satellite technology during the past few decades has been a tremendous asset to understanding the many factors that influence Earth's climate. This is particularly true with clouds and their influence on weather and climate. The role of clouds is twofold; they trap heat near the Earth's surface to warm it, and they reflect solar radiation to cool the Earth. Only recently did scientists come to understand how prevailing the influence of clouds is on climate. Preliminary results from NASA's Earth Radiation Budget Experiment (ERBE) have destroyed many past misconceptions. It has been discovered that the role of clouds on climate differ not only by type, but by location [5-16].

It is generally known that clouds are instrumental in redistributing heat from the equator toward the poles, and transporting water to other locations. However, gaps in our understanding of clouds' impact on Earth's radiation budget still exist. In the tropics, towering cumulonimbus clouds can reach up to 10 miles in the atmosphere. These clouds are excellent trappers of heat, and reflectors as well. It has been estimated that they trap three times the amount of heat than the global average for all clouds. But they reflect just as much heat, so there is a zero net change in heat over the tropics.

There is serious concern though, about changes in the radiative properties of these towering clouds in a warmer world. It is likely that there will be more cloudiness with the warming. However, the clouds would extend higher into the atmosphere where the tops of the clouds would be much colder. The colder tops would reduce the clouds' ability to radiate heat into space. There may also be a change in the general circulation pattern induced by increased cloudiness, and more heating near the surface due to the efficiency of the cumulonimbus in trapping heat below the clouds' base.

Another important cloud group that contributes to Earth's radiation balance is stratocumulus. This cloud group is particularly common over much of the world's oceans, in latitudes higher than 30$^{\circ}$ north, and usually off the west coasts of continents in the northern hemisphere. It has been discovered that the stratocumulus, unlike the tropical cumulonimbus, contribute a negative balance to the total Earth's energy balance. It is believed that the reflectivity of these clouds is almost three times more of what was formerly believed. These are generally formed in stable, high pressure regions, around sulfate nuclei, and generally exist between 1 and 2 miles above the earth's surface.

A third major group of clouds that have dismayed many experts are cirrus clouds. At one time it was believed that these were efficient heat trappers, but now their effect is viewed to be the opposite. These clouds are able to reflect more heat than they trap because of the ice crystals they contain.

Knowledge about the clouds' role in GCC should increase dramatically due to the amount of research dollars being directed to it. The clouds influence on the world's climate is pervasive. Over 50% of the globe is covered by clouds, and they account for about two-thirds of the planetary albedo [5-17]. Any impact on the development, location and type of cloud as a result of GCC could have a profound and rapid effect on Earth's physical and biological processes, and further enhance GCC from the clouds' climate feedback mechanism.

## Glaciers, Snow, and Ice

The world's glaciers, ice sheets and sea ice, and snow regions have great impact on GCC, and are influenced by it as well. Like clouds, the polar regions have a dichotomous nature. For example, if global temperature increased, there would be more water vapor transported poleward from the mid-latitudes. Because water vapor is an efficient greenhouse gas, it would absorb heat and decrease net radiation loss. This process would then add to the already increasing temperature at the poles. The increased warming would melt more snow and ice, leaving more bare ground to absorb even more solar radiation, increasing temperature further.

Alternatively, increased water temperatures would lead to increased evaporation and cloudiness. This would then reflect more incoming radiation, and precipitation would replenish the snow and ice sheets [5-18]. The poles' albedo would increase and reflect even more solar radiation back to space, cooling the poles further.

There are indications that global warming is occurring, and manifesting itself in many ways. Some observations are [5-19]:

- The depth to the permafrost in the Alaskan and Canadian Arctic has increased.
- The average temperature of Canadian lakes has increased.
- There is a general decrease in sea ice surrounding Antarctica and in the Arctic seas.
- Inland glaciers throughout Europe and other parts of the globe have receded.

A British Antarctic Survey team at Rothera has recorded a significant loss of snow and ice in their region [5-20]. Their observations show that since 1982 there has been a $1^{o}$ rise in mean summer air temperature. Their explanation was that these changes were not a result of the greenhouse effect, but of a natural warming cycle that at the time of the report was supposed to be at its peak, but this analysis is more qualitative than quantitative.

The reflectivity of snow and ice in the Polar regions is so crucial to the climate, that a small change in sunlight in these regions can produce amplified changes in radiation and temperature. Even adverse human activities can cause local climate effects. Another Exxon Valdez accident at a higher latitude or a similar disaster over land would provide a dark surface by which radiation could be absorbed, and lead to local melting and a disruption in the area's climate [5-21].

Recent satellite studies over Greenland provided very surprising results. During the 1980's when record high global temperatures occurred, the Greenland Ice Sheet grew. As reported by Zwally [5-22], and alluded to earlier, increased precipitation occurs with warming. In this case the increased precipitation came in the form of snow that more than compensated for any melting of the ice sheet that occurred.

Zwally cited other studies that suggested that for every degree Kelvin increase of temperature, there could be a commensurate increase in precipitation of 5 to 20%. This would affect the ice-sheet mass balance. The equilibrium line that separates the zones of ablation and accumulation would essentially be unchanged in a warming environment. Increases in precipitation and cloudiness resulting from a warming episode would more than compensate for changes due to rising temperatures alone.

Apparently, the snow pack in Europe has some influence on the intensity of the Indian monsoon. In a study using GCMs on the effect of Eurasian snow cover on global climate, it was determined that a teleconnection may exist, and that this link depended on the extent of the snow cover [5-23]. With above normal snow coverings, the Indian monsoon has less rainfall and the winds are uncharacteristically low, and the surface pressures are higher over southeast Asia. Whether this plays a part in the ENSO event is not known, but snow covering over the globe has a definite influence on Earth's climate.

## Rain Forests

A study of the Amazon rain forest indicates that the rain forests have a significant role in a region's climate. The findings of Shukla, et al., demonstrate the importance and sensitivity of resources on a region's climate, such as the Amazon [5-24]. To determine the impact of current deforestation practices in Brazil, a GCM was coupled with a biosphere model. The model was run twice to simulate two scenarios. In one run the Amazon region was covered with tropical forests. In the second run, the rain forest was replaced by degraded pasture covered by grass. A comparison of the two computer runs showed that in a deforested case, the area would experience increases of up to 2.5°C in surface temperatures, a longer dry season, and a 26% reduction in precipitation.

If deforestation practices were to continue, the Amazon region would incur a considerable disruption in its energy balance and hydrologic cycle. The consequences would include more frequent and intense forest fires, a loss in the diversity of plant and animal life, and the loss of a significant sink for ozone, $CO_2$ and other trace gasses. The bottom line is that the destruction of the Amazon rain forest may be irreversible. The loss of the rain forest could cause a permanent change in the normal atmospheric flow patterns that advect moisture from the oceans to maintain its existence, and the plant and animal interactions could be so complex that once lost, they could not be replicated.

## Sunspots

There has always been controversy with regard to sunspots and their influence on the world's climate variability. It is known that there is an 11-year sunspot cycle, and the results from the Solar Maximum Mission showed that the variance in the sun's energy output during the course of a sunspot cycle was only 0.1% [5-25]. Despite this seemingly low variance in solar output, Labitzke, et al., demonstrated that there was a statistically significant connection between sun spot cycles and variations in weather. They found that mild winter warming in the U.S. and western Europe correlated very well with the solar cycle over the past 40 years, but there has been serious doubt cast upon this report.

Geller [5-26] pointed out that no physical mechanism has been identified that is capable of quantitatively explaining any effects of solar activity on the lower atmosphere. Others had performed statistical correlations similar to Labitzke's, on atmospheric data to simulated harmonics of arbitrary period, to show the weakness of such arguments without having physical mechanisms present to study. The atmosphere does exhibit variations on a time scale that spans a decade as a result of long-lived, non-random effects, but this does not imply that other forcings with similar periods are at work [5-27].

## Volcanoes

Volcanic activity can influence climate regionally and globally, and its effect can last for years. A volcano's effect is not limited to the atmosphere, but they influence the ocean's thermal properties as well. Recent work by Mass and Portman [5-28] have illuminated the interactions of the atmosphere and oceans after volcanic eruptions.

It has been found that the influence of a volcanic eruption is limited on a global scale. Typically, its influence is only felt in the hemisphere in which the eruption occurred. This is due to the limited spreading of the plume. After a large eruption, the plume does not cover the hemisphere uniformly. Instead it is generally confined within the latitude of the eruption, and spreads slowly.

Additionally, only the largest eruptions that generate stratospheric dust clouds will cause cooling in the order of $0.1^{o}$-$0.2^{o}C$ for a period of 1-2 years after the event, but there is no appreciable impact on either pressure or precipitation. A response in the oceans, however, lags behind the atmospheric response. It takes about 10 months for sea surface temperatures to decline by a quarter of the air temperature decrease, and 4-5 years for sea surface temperature to return to steady state after a change in the solar forcing has occurred.

Not all explosive volcanoes initiate such changes. Mount St. Helens, for example, had a limited impact on Earth's climate due to its explosive force being directed more horizontally than vertically. The injection of aerosols into the stratosphere is important for long-term effects. These effects attenuate the incidence of solar radiation by 20-30%, and takes 2-3 years for the aerosol levels in the stratosphere to decrease toward pre- eruption levels.

Some have questioned these findings, expecting that volcanic influence on climate would be considerably greater. Often cited as an example is the eruption of Mount Tambora and the 'year that had no summer'. Mount Tambora, an Indonesian volcano, erupted in 1815 and injected an enormous amount of ash into the stratosphere. The summer of 1816 turned out to be a disaster for agriculture. Both the North American and European continents were affected with extreme cold temperatures, and it snowed in Boston that summer.

According to Flam [5-29], the cold snap could have stemmed from some unidentified aberration in nature. As shown earlier in this chapter, the ENSO event imposes considerable change in the climate system.

Schneider offered another explanation [5-30]. He admitted that Mount Tambora had played a part in this cold summer, but the degree of influence is not certain. Ship passage records of the Hudson's Bay Company during that year revealed that ice jams in Hudson Bay occurred in the summer of 1816. Schneider reasoned that there existed an abnormal summertime northerly wind over North America, and the jetstream was displaced far from its normal summertime position, forcing cold arctic air over these two continents. There may have been other factors, such as an ENSO event, that perturbed the normal climatological mean of pressure systems and wind flow. The ENSO event, in conjunction with the eruption, may have led to this occurrence of a year without a summer.

The oceans are also influenced directly by erupting undersea volcanic events. A report in the Environment [5-31], suggested that underwater volcanoes could force an ENSO event. It is thought that an imbalance would occur in the general circulation of the oceans and the atmosphere due to the tremendous amount of heat release deep in the oceans, and thus begin an ENSO event. Findings of increased lava flows, and increases in the number of earthquakes around Easter Island have helped to bolster this theory.

There are many factors within the Earth system that influence global climate. The effect of these events individually can cause permanent and unwanted change. There is no clear understanding, though, of the resultant change if more than one event occurred simultaneously, as may have occurred in the year without a summer. Efforts are underway to gain this understanding through simulations of Earth's climate system with the use of GCMs. The model's capabilities are very limited at present, but great strides in improving them have been made in the past few years, and many new discoveries are anticipated in the very near future.

# TOOLS FOR THE PRESENT AND FUTURE

The best tool used today to simulate the Earth's future climate is the general circulation model (GCM). Other techniques have been developed to model the world's climate, but none of these alternatives can describe realistically today's changing environment [6-1]. This model, which runs on a super computer, describes the physical processes of the atmosphere and its interactions with the ocean and land. The basic laws of thermodynamics and hydrodynamics drive the model, and provide the means to calculate the flow of atmospheric gasses. Other fundamental relationships are factored into the model, such as the transfer of heat through the atmosphere and the reflectivity of various surfaces.

GCMs are used to simulate future climate. They are also used to determine the direction and magnitude of change between Earth's present climate and simulated climate in an effectively doubled $CO_2$ environment. The term 'effective doubling of $CO_2$' is used interchangeably in this paper with doubled or twice $CO_2$ concentrations. This term is used to describe the net effect of all greenhouse gasses in the atmosphere on the greenhouse effect. The effective doubling is reached when their net influence on the greenhouse effect equals the same effect of twice the preindustrial $CO_2$ concentration alone. Further, the GCMs only calculate the effects of changed concentrations of greenhouse gasses. GCMs do not predict when this doubling of $CO_2$ will occur. That prediction is left to other scientists to determine. It is believed, however, that the effective doubling of $CO_2$ will occur around the years 2030 and 2050. This time range is tenuous as it is greatly influenced by societal activities globally.

A typical model divides the Earth's surface into 800 to 11,000 rectangles or grid points. The atmosphere is also divided into 2 to 15 layers [6-2]. Estimated mean values for wind, temperature, solar radiation, relative humidity and precipitation are calculated for each grid point, but their frequencies are not computed [6-3].

The GCMs are useful to test the sensitivity of climate to different conditions, and to provide the input needed to run other regional models that have a fine mesh grid. These regional models simulate the response of forests, wetlands, and water management systems to changes in predicted climate variables.

There are four modeling groups in the U.S.: Oregon State University (OSU), NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), NASA's Goddard Institute for Space Studies (GISS), and the National Center for Atmospheric Research (NCAR). The United Kingdom Meteorological Office (UKMO) also owns and operates a GCM. Each agency has worked independently to develop its own model. All of these models

Table 2: GCM PREDICTIONS OF GLOBALLY AVERAGED CLIMATE CHANGE DUE TO DOUBLED $CO_2$ (APPROXIMATELY IN THE YEAR 2050)

| [illegible] | [illegible] | [illegible] |
|---|---|---|
| GFDL | 4.0 | 8.7 |
| GISS | 4.2 | 11.0 |
| NCAR | 3.5 | 7.1 |
| OSU | 2.8 | 7.8 |
| UKMO | 5.2 | 15.8 |

(Source: Environmental Protection Agency, December 1989)

are in close agreement estimating the relative change of temperature in a double $CO_2$ environment, but there is a wide spread in precipitation values shown in table 2.

Disparity between the models also occurs when a comparison is made of their results for seasons, as shown in table 3. All four U.S. models show different results for the summer and winter scenarios. GCM results for global average temperature usually agree well. The results diverge when the spatial or temporal resolutions are increased. There is also a lack of consensus when a comparison is made of the other variables that are computed by the GCMs.

There are many who have openly questioned the validity of the results calculated by GCMs for a doubled $CO_2$, such as the warming of the atmosphere by $2^{o}$-$5^{o}C$. It has been pointed out that current weather predictions can only be extended out to three days with any degree of confidence. There is a significant decrease in the model's skill when the forecast period exceeds three days. So why should anyone believe the GCM, which has a much coarser grid and more limited modeling skill than the latest state-of-the-art weather forecast models?

There are several good reasons why GCMs are valuable tools for use in simulating climate. First, their skill at simulating the climate on the planets Mars and Venus have been successfully validated. Second, they perform well in the simulation of Earth's geologic record. Third, they provide the means to study in detail the dynamics and interactions of known processes that act on Earth's climate system. However, they are far from having the precision needed to produce forecasts with any high degree of confidence. Instead they are used to describe possible scenarios from which the im-

Table 3 : Differences of temperature estimates for four GCM's and observed temperatures

| Variable and model | Global | N. America | Contiguous U.S. | Midwest U.S. |
|---|---|---|---|---|
| | | Domain of comparison | | |
| | December-January-February | | | |
| Observed median temperature (℃) | 8.5 | -5.8 | 0.9 | -1.5 |
| Difference in median temperatures (GCM - Observation) | | | | |
| GFDL | -1.6 | -0.3 | -2.1 | -0.5 |
| GISS | 1.5 | -1.8 | -0.8 | -1.3 |
| OSU | 0.8 | -0.5 | 0.0 | 1.1 |
| NCAR | 0.3 | 0.5 | -0.6 | -1.0 |
| | Jun-July-August | | | |
| Observed median temperature (℃) | 13.9 | 18.9 | 23.0 | 23.0 |
| Difference in median temperatures (GCM - Observation) | | | | |
| GFDL | 1.3 | 6.0 | 6.3 | 6.8 |
| GISS | -0.2 | 0.6 | 0.1 | 3.7 |
| OSU | 0.4 | -3.1 | -4.5 | -4.8 |
| NCAR | -0.6 | -2.2 | -2.2 | -1.6 |

(Source: Environmental Protection Agency, December 1989)

pacts of climate change can be assessed. GCMs provide researchers a blurry view of the world's future climate.

There are two major limitations that GCMs have in depicting climate. One is their low spatial resolution and the second is their inability to resolve climate elements on a regional scale.

The spatial resolution of most GCMs is approximately 400Km by 400Km, roughly the size of Colorado. With such a low resolution, there are only 50 grid points that cover the U.S. The temperature, precipitation, and other meteorological variables are averaged to a single number for quite a large area.

The problem of the spatial resolution causes the models to have a distorted view of the U.S. and the globe. The U.S. is seen as a continent with only one mountain in place of the Rocky Mountain range. The height of the 'mountain' is not as high as some of the peaks in the range. With such a large grid, the models do not see Florida, or the Appalachian and Sierra Nevada Mountains. Globally, the GCMs do not see Japan or Korea. Its geographical view of the world is very simplistic. Therefore it is unable to capture any of the mesoscale features that have significant impact on a region's climate such as terrain, or take into account effects of urbanization and industrial pollution.

The large grid size also prevents the models from determining or taking into account the existence of other important meteorological phenomena that do not have a large areal coverage. Hurricanes and tornadoes are two such natural occurrences, whose change in intensity, location and frequency of occurrence would have a definite impact on regional and global climate, and on societal activities. There are other significant natural occurrences in the Earth system that have a definite impact on climate whose areal extent is smaller than the model's grid size. Storm fronts, atmospheric chemical reactions, cloud type and coverage, and forested areas are examples of these small sized natural occurrences. As a result, many physical and biological processes that influence climate on subgrid scales are either overly simplified, or ignored.

The GCMs have problems accurately describing physical processes. For example, one nagging problem faced by modelers is how to account for all the processes in the radiative heating of trace gasses. They must cope with the inaccuracies in basic radiative parameters provided by laboratory studies, work with approximations in radiative transfer models, take into account spectrally overlapping absorbers and their growth rate, and much more [6-4]. GCMs also have difficulty with cloud cover, changes in the atmospheric stability and moisture distribution, and changes in the sea-ice cover and its radiative effect.

Clouds present a unique problem in modeling due to their prevalence around the globe, and the changing reflectance of the clouds based on cloud type. Reflection of solar radiation by clouds depends on their optical thickness. The thermal infrared emission of clouds depends on the cloud top temperature and cloud emissivity. The difficulty in modeling clouds results from typical clouds being subgrid scale, and thinner than model layers. The horizontal scale of typical clouds is between 1-100 Km, whereas the GCM grid scale is 400 Km. There is also a wide variety of cloud types with varying radiative properties, which undergo diurnal changes.

A recent study found that there was a great difference in opinion among modelers about the effect of clouds on climate [6-5]. This study compared results of 14 GCMs from six countries. All the GCMs were run under clear sky conditions. There was good agreement among all the GCMs in forecasting global warming induced by greenhouse gasses. When the influence of clouds on climate was restored in the GCMs, the resulting temperature forecasts diverged in magnitude and direction.

Clouds have a dominant role on the climate system by governing the albedo of the earth (the percent of incident solar radiation that is reflected back into space). Preliminary results from the Energy Research Budget Experiment (ERBE) showed that clouds have a net cooling effect on Earth's climate [6-6]. Most of this cooling was found to occur where clouds formed in association with storms, and along the track of storms over oceans. In other parts of the world there was essentially no net gain or loss in the accumulation of heat. Still, not enough is known to adequately model clouds in a changing climate, or the radiative effect of multilayered clouds.

A recent report showed that improved cloud modeling reduced the sensitivity of a GCM to a doubled $CO_2$ environment when the amounts of ice-crystal and water-vapor clouds are changed[6-7]. The GCM was coupled with a 50-meter ocean layer. The old cloud model used in the GCM, based on relative humidity, was replaced by a more sophisticated model. The results, as summarized by Slingo [6-8], showed that the average equilibrium surface warming in a doubled $CO_2$ was halved from 5.2°C in earlier runs to 2.7°C. When the radiative properties of the clouds were allowed to depend on the liquid-water content, the warming dropped further to only 1.9°C. This study demonstrates how the realism of the GCM is enhanced with improved parameterization of underlying processes that determine the world's climate.

When this same GCM was run to simulate the world's present climate, the global average warming to date was calculated to be 0.6°C. This is within the observed range of average temperature change of between 0.5°C to 0.7°C. Earlier runs, prior to the more sophisticated cloud model, calculated that the warming to date should have been from 0.5°C to 2.0°C [6-9].

Understanding the high latitude response to climate change is also crucial to the development of realistic GCMs. The polar regions account for the greatest share of the observed and expected changes in the world's temperature. Modeling this behavior correctly is therefore very important to simulate the climate system's response to increased levels of greenhouse gasses. Sea ice and snow, though, are poorly modeled. They are treated as a single slab over a mixed layer ocean, and the albedos of the snow and sea ice fields are oversimplified. There are many questions yet to be answered about the environmental processes that affect polar climate before significant improvements to the GCMs can be achieved.

The surface hydrologic response is another important process that is poorly parameterized. There is wide variance in the different models concerning this mechanism. A new approach to modeling the hydrologic process was described at the Global Change Conference in Anaheim in 1990 [6-10]. The Department of Energy is sponsoring a study using NCAR's Community Climate Model (CCM, the same as a GCM). A fine mesh mesoscale model was developed to improve on the CCM's modeling of the hydrologic processes and to refine the model's spatial resolution. The mesoscale model greatly improved on the CCM's topography by showing the Sierra Nevada and Rocky Mountain ranges. These mountain ranges exert tremendous influence on the climate and hydrologic cycle in the area under study in the Southwest U.S. Initial results of this modeling scheme were reported to be encouraging, but the review process is still underway.

The ocean and its interactions with the other components in the Earth system is another area where we lack knowledge and understanding of how the climate system operates. The GCMs, again, treat the air-ocean interface simply. Earlier models viewed the oceans as a swamp, or a slab that was not dynamic, and they held sea surface temperatures and salinity nearly constant. Recently, attempts have proved successful at linking GCMs with ocean models that simulate the dynamics of the mixed layer in the oceans, approximately the upper 50 to 200 meters of the ocean. The results from the linked GCM and ocean models showed a temperature increase between preindustrial global average temperatures and a doubled $CO_2$ environment. However, the temperature increase viewed from the linked models was less than that observed from running the GCM model alone. The vertical motions of the oceans that take heat and trace gasses down to the deep ocean are not well understood or modeled. The GCMs oversimplify real world processes and ignore the influence of the deep ocean.

There is evidence that alterations in the deep ocean circulation have been responsible for rapid climate changes. As noted in an earlier chapter on the glacial record, the changes in the deep ocean's movement had resulted in dramatic changes in glacial movements and the development of the St. Lawrence River. Glacial periods in Earth's history have been found to end abruptly, which may have been caused by changes in the deep ocean. The influence of ocean current patterns also are the cause of tremendous global stress during ENSO events as described in the previous chapter.

A major block to coupling the general circulation model of the ocean to the GCMs is the lack of knowledge of the physical and biological processes in the ocean environment, the lack of computer power needed to drive such an immense model, and insufficient data to run the models. It is currently believed that the heat capacity of the oceans will delay the eventual warming of Earth's atmosphere, but again there is a lack of certainty.

As mentioned earlier, these models run on supercomputers. The reason they use such large grid sizes is that they have to economize the computer's time. In addition, there are no super computers that are dedicated to the use of GCMs. It was reported that one well known modeler, Schlesinger, competes with 1,500 other users for computer time [6-11]. The effort to modify, and improve the models is therefore severely constrained. As a matter of note, West Germany has a dedicated supercomputer for work on their GCM.

The field of climate modeling using GCMs has been forced to grow up quickly in response to perceived changes to the world's livelihood in the coming century. The models themselves are imprecise due to the oversimplified permutations of complex processes about which little is known. More sophisticated models require greater computer power than is available to run. However, these models are the best tools we have to simulate future changes and assess their impacts. There have also been many recent improvements to the GCMs based on advances in our understanding of the processes and interactions in Earth's climate system. GCMs are a powerful tool when used properly.

# POSSIBLE SCENARIOS FOR FUTURE CLIMATE

The global circulation models, as discussed in the previous chapter, are useful tools to simulate future climate so that impacts from predicted changes can be assessed. However, they should not be considered as forecasts of what climate will be, rather, what it may be like based on the best knowledge and technology available today. In addition, the timing of when the effect of doubling the preindustrial level $CO_2$ is not calculated by the GCM's but is instead estimated based on assumed trends in anthropogenic forcings. The timing of when there will be a doubling in preindustrial level $CO_2$ is expected to occur in the middle of the next century. Any changes in the assumed trends in human activities will have a definite effect on when the doubling will occur.

## Past Experiences

There is precedent to the problem we now face evaluating the likelihood and extent of a warming planet. Similar concerns and debate occurred in the early 1900's when average global temperatures were rising. Wallen [7-1] summarized some of the observations to demonstrate the impact of general warming on the high latitude region of the North Atlantic. Environmental and economic repercussions were realized as a result of the changes in the migration and behavior of plant and animal life, and societal adjustments.

A major industry in that era and location was fishing. The warming climate forced the northward migration of normal fishing areas from between $60^{o}$ and $65^{o}$N in the 1920's, to 300 Nautical Miles north within 10 years. Cod were found in areas where they had never had been observed around the Greenland and Spitsbergen waters. They also left normal breeding areas. Many communities that lined the northern Atlantic basin benefited from such a dramatic move, while others could not avoid the associated hardships from a reduced, or distant harvest of fish.

The effects of the warming were noticeable on land. There was a general increase in the vegetation growing season, and a migration of various plants, trees, and animal species toward higher latitudes. Increased pestilence was also observed.

Reacting to the seemingly good fortune of having a longer growing season, Finland had developed and engaged in reforestation activities. They unfortunately could not recognize that another adjustment in climate toward cooler temperatures was just a decade or two away, and would last from the 1940's through the 1960's. They suffered many failures in these programs during the cooling period in the mid 1900's. Agricultural practices suffered a similar fate. During the warming trend they pushed the northern boundary of farming further north. When the cooling trend began, the new settlers and farming communities had to eventually abandon their farms. The cooler climate could not sustain the growth that was temporarily available during the warming of the 1920's and 1930's.

Part of the debate during the warming trend concerned its process. The argument centered on the possibility of changes in the general circulation pattern that greatly increased the transport of heat from the mid-latitudes to the polar regions. However, there was no certainty in the processes that produced the climate change nor certainty in future trends. Lacking any of the tools that now exist, policy makers of that time committed their countries to policies and development strategies that became ineffectual within years of their implementation.

Major efforts are underway today to support scientific research in fields related to climate change, and to link scientific knowledge with policy. Such efforts are designed to avoid the shortcomings of past practices. Many significant findings have been reported from the expanded research efforts on the response of the Earth system to climate change, and are reported here.

# GCM Results

Typical computer runs on the GCMs simulate what climate will look like in a doubled $CO_2$ environment. The National Academy of Sciences reported on the scientific confidences in predictions of how Earth's system would respond to an environment with doubled $CO_2$ (National Research Council, 1987). Table 4 was extracted from the Environmental Protection Agency's report to Congress [7-2], and a report by Wood[7-3]. Both listed the summary of findings by the National Academy of Sciences.

Hansen [7-4] reported to a congressional hearing in 1986 on the effects of a warming climate on potential temperature extremes in the U.S. It is expected that the incidence in the number of days that temperature exceeds 90°F will generally increase over what is has been observed since the mid 1980s. Table 5 provides a brief list of major cities in the U.S. and what they might expect in a doubled $CO_2$ environment.

Other studies and conferences have also attempted to gauge the direction and magnitude in climate change for the U.S. A committee formed to study climate change by the American Association for the Advancement of Science (AAAS) in 1988 reported several probable impacts from a 2°-5°C increase in average global temperature on water supplies in the 48 states [7-5]. They found that:

- Some states will be wetter than others,
- Summers will be drier in the interior of the U.S.,

Table 4: Possible climate responses to increased greenhouse gasses.

Large Stratospheric Cooling (virtually certain). The combination of increased cooling by additional $CO_2$ and other trace gasses, and reduced heating by reduced ozone, "will lead to a major lowering of temperatures in the upper stratosphere."

Global-Mean Surface Warming (very probable). For an equivalent doubling of $CO_2$, "the long-term global-mean surface warming is expected to be in the range 1.5 to 4.5°C."

Global-Mean Precipitation Increase (very probable). "Increased heating of the surface will lead to increased evaporation and, therefore, to greater global mean precipitation. Despite this increase in global average precipitation, some individual regions might well experience decreases in rainfall."

Reduction of Sea Ice (very probable). This will be due to melting as the climate warms.

Polar Winter Surface Warming (very probable). Due to the sea ice reduction, polar surface air may warm by as much as three times the global average.

Summer Continental Dryness/Warming (likely in the long term). Found in several, but not all studies, it is mainly caused by earlier termination of winter storms. "Of course, these simulations of long-term equilibrium conditions may not offer a reliable guide to trends over the next few decades of changing atmospheric composition and changing climate."

High-Latitude Precipitation Increase (probable). The average high-latitude precipitation is projected to increase due to enhanced poleward penetration of warm, moist air.

Rise in Global Mean Sea Level (probable). This will be due to thermal expansion of seawater and melting or calving of land ice.

**(Source: Environmental Protection Agency, 1989, and Wood, 1990.)**

- Effects from a warming climate would be felt hardest in the arid west,
- It will be difficult to maintain the current level of irrigation in the west,
- Water is expected to be abundant in the east, but areas under irrigation will increase,
- Greater amounts of $CO_2$ in the free atmosphere will cause plants to grow faster and reduce water that escapes from leaves,
- Present storage systems for water are likely to become inadequate in some places,
- There is a definite problem with managers of urban water systems who feel that climate change is not an immediate concern.

Table 5: Number of days with high temperatures > 90° F.

| [illegible] | [illegible] | [illegible] |
| --- | --- | --- |
| District of Columbia | 35 days | 85 days |
| New York City | 15 | 48 |
| Memphis | 65 | 145 |
| Dallas | 100 | 162 |

(Source: Levenson, 1989)

The immediacy of the problem of water in the U.S. was underscored by the fact that there are many third world countries striving to reach some level of economic parity with other developed nations. The additional strain on Earth's environment from freely and aggressively injecting greenhouse gasses into the atmosphere is not their major concern. The U.S. cannot solve the problem of increasing greenhouse gasses in the atmosphere by itself. This is a global problem. The U.S. can have a strong influence delaying the full impact of rising concentrations of these gasses by developing effective domestic policies, and leading the way toward generous sharing of technologies with developing countries to reduce their output of greenhouse gasses.

## Atmospheric Patterns

A study conducted by Rind, et. al., [7-6,7] shows some of the direct influences global warming could have on large scale weather systems and air pollution. Under a typical warming scenario, the polar regions would warm more than the tropics. This event would lead to less thermal contrast latitudinally, and thus retard the intensity of storms. Strong thermal gradients are needed for storms to intensify and distribute moisture and heat about Earth in the mid-to upper latitudes.

These storms would also tend to move more slowly, thereby allowing an airmass to spend more time over a particular region. The more time a homogeneous airmass remains over an area that is heavily industrialized, the more likely the concentration of harmful gasses and associated illness will increase. Not until the polluted air mass is replaced by a cleaner airmass will the ill effects of the polluted air be diminished. It has also been determined that in a warmer climate reactions between sunlight and air pollutants in the troposphere will occur at a faster rate, increasing the amount of photochemical smog across the U.S.

Precipitation patterns are expected to be affected as well. In a doubled $CO_2$ environment there could be a 30% to 40% increase in humidity. Though there would be a greater amount of evaporation of ocean water, and an increased hydrologic cycle, the precipitation patterns are expected to become highly regionalized. Areas in the U.S. that rely on rain for their irrigation, such as in the Midwest and southeast U.S., may encounter unaccustomed harsh conditions. As the temperature increases, so will the evaporative process. In these farming regions it is expected that what rain falls over these lands will quickly evaporate and leave them drier than normal.

The effects of dryer land areas on wildlife was evident during the drought in 1988 [7-8]. It was reported that wetlands and ponds for migrating birds were greatly reduced. The duck population fell to an all time low. The population of Pintails was down 64%. Part of the concern was that such heat stress would adversely impact on the birds ability to forage, maintain their strength, and to breed. Lower water levels also exposed many toxic materials that wildlife were able to consume and suffer from. Many dangerous situations developed when land animals migrated from their normal foraging areas to populated areas looking for food and water. There are now organizations that are engaged in the formulation of plans in concert with city and state governments to plan and attempt to mitigate the effects of GCC.

# Vegetative Responses to GCC

There are many critical factors that determine the success of agriculture and forest management efforts in response to GCC. Future strategies will need to be developed that effectively deal with expected changes in temperature, $CO_2$, precipitation, evapotranspiration, and soil moisture to be able to cope with heat and drought stresses that may occur in some areas of the U.S. The U.S. Forest Service is developing comprehensive research efforts in anticipation of the potential threat of global climate change. Not only is it important to study the effects GCC has on the biosphere, but also the biosphere's influence on the direction and magnitude of GCC.

GCC is influenced by biosphere feedback mechanisms through its production of greenhouse gasses. Peatlands, for example, typically capture and store carbon. Yavitt and Wieder found, however, that the amount of sulfates in the bogs, such as in West Virginia's Big Run Bog, are increasing from acid rain. This imposes an environmental stress that favors sulfate reducing bacteria (SRB) over the indigenous methanogens (methane producing bacteria). SRBs produce $CO_2$ in great quantities that are released into the atmosphere rather than being stored by the plants, which further adds to the greenhouse effect. It was determined that SRB's are 1-1/2 times more efficient as $CO_2$ producers than methanogens. Acid rain is also luring SRBs into other wetlands and converting these sinks for $CO_2$ into sources of $CO_2$ [7-9].

Peatlands are estimated to hold 15% to 20% of the land stored carbon. But as the land dries, the holding capacity of these areas would diminish. This scenario becomes even more bleak if these peatlands are colonized by oxygen using microbes that decompose carbon based plant debris.

The ability of America's forests to withstand the forcings associated with GCC are also questionable. It has been reported that Earth's forests do not hold as much vegetation as has been commonly believed. As reported by Botkin [7-10] there have been no statistically valid estimates of biomass for any large area of the Earth. In his study of the boreal, he found that it contained 1/3 the carbon reported by most surveys. The forests are needed to capture carbon for ecosystem services such as erosion protection and water holding capacity. To better estimate the growth of $CO_2$ in the atmosphere, more accurate measures of the world's biomass are needed. That way more reliable calculations of $CO_2$ uptake by the worlds biomass, and quantification of Earth's carbon cycle can be achieved and modeled.

Davis [7-11] reported on the findings of simulation models and investigation on the process of forest succession and how it relates to GCC. She reported that in an experimental $2^{o}C$ warming scenario, there was an immediate change in the underbrush, but a century long migration of canopy trees. The growth response of individual trees were found to be rapid, but the response by the forests were found to lag by decades due to inefficient seed dispersal. The fossil record shows a dramatic and quick response by the forests when temperatures fell during the Younger Dryas cold period 10,800 years ago. There was no lag because the temperature was cold enough to kill the trees within a very short period of time relative to a tree's life span. 500 years later, at the end of the Younger Dryas, there was an abrupt change to a warmer climate and a halt to silt and clay sedimentation. This induced an immediate response by shrubs and other forms of low lying vegetation. However, the fossil record showed that there was a noticeable lag in the tree response to the warming. The slow response was due in part to slow seed dispersal and a lag in soil development. Today's forests would also have to contend with slow dispersal due to a reduced seed source, a result of logging practices, and human geographical disturbances.

Vegetation may respond to climate warming through adjustments in competitive relationships if there is a moderate rise in temperature, but changes by trees may not be visible for decades. It is thought that in a warming scenario, the southern boundary of forests would move northward and be replaced with grasslands [7-12]. The rate of change in the geographical distribution of trees in response to a warming climate is a northward expansion of 100Km per $1^{o}C$ increase. Fossil records show that temperature changed by a few degrees over a thousand years. Today's concern is that this same change in temperature will occur in only 100 years, and force trees to respond at unprecedented rates, or approximately ten times the historical rate. This does not imply that the historical rate is the maximum rate at which vegetation can respond. It follows then, that with a projected temperature increase of about $3^{o}C$ for the coming century, the tree advance would have to average 300Km per century to survive. The net result, is that we face a loss of diversity on the regional basis as species become extinct in marginal areas.

Another simulation conducted by Running [7-13] found that forests in the mountains of the western U.S. should do well in a warmer climate. In a doubled $CO_2$ environment with temperature 4°C warmer, and a 10% increase in precipitation, they found that the tree growth should increase 20%-30%. He also found that the western snow packs will thaw 60-80 days earlier in spring. This event by itself would place tremendous hardship on cities that rely on these watersheds holding these waters for longer periods. To add to the problem of the early thaw, these forests would also consume more water because of their increased growth, impinging further on water supplies for human consumption.

Vegetation response to increased $CO_2$ is not the only problem we face in the coming century. As these plants grow faster in air with doubled $CO_2$, they will have more carbohydrate based tissue and less protein. Insects that feed on these will be affected. It was found in studies that the Buckeye-butterfly larvae consumed 15% more vegetation, took 10% longer to reach pupation, and were visibly weaker when feeding off of plants that were raised in the doubled $CO_2$ environment. Other studies showed that the cabbage butterfly larvae needed 43% of the doubled $CO_2$ plants to maintain their growth rate, and sage brush grasshoppers needed 36% to 58% more food to maintain their growth rates [7-14]. Not only would their appetite increase, but the pestilence would migrate northward as well with a warming climate. It is still unclear, however, whether the increased growth of plants in a doubled $CO_2$ environment will compensate for expected increases in predation.

# Regional Impacts

Environment Canada has been actively pursuing an understanding of what impacts GCC would have on their agriculture. Their findings suggest for the Ontario region that [7-15]:

- There may be crop failures,
- In northern Ontario the number of crops that can be grown could increase, whereas in the south, growing corn and soybeans may become very risky,
- Horticultural crops may replace other grain crops in southern Ontario,
- There may be higher profits, but greater risks for Ontario farmers,
- Without adjustment, the greenhouse effect could cost Ontario agriculture $170 million per year in lost production.

Similar results for GCC could occur in the U.S. For example, in the southeastern and mid-west U.S. drought resistant plants would need to be grown in place of customary crops. Another severe limitation on what is grown and where in the U.S. may be the water management systems. These systems could become ineffective due to climate change, or needs may arise rapidly in areas where such systems do not exist.

Williams [7-16] wrote on some of the problems we face with regard to water resources in the coming decades if climate changes within the realm of present projections. Such changes include a 60% increase in average runoff between $40^{o}$-$60^{o}$ latitude in a doubled $CO_2$ environment. The effect of this change on average annual flow, annual variability of flow, and seasonal distribution of flow could either overwhelm existing systems or convert them into inefficient systems. Williams identified a few geomorphic effects that illustrates how serious a problem this could become:

| | |
|---|---|
| Arid Climates | A 10% increase in precipitation can increase sediment delivery by 100%. |
| Wet Climates | Increased precipitation in deforested or unforested hills can increase landslides and increase sedimentation in waterway systems. |
| Semi-arid Climates | Increased runoff initiates massive gullying and riverbed down cutting. Reservoirs have shorter life spans due to decreased storage capacity from increased sedimentation. Aquifers would not be recharged as frequently, reducing their long-term yield. |

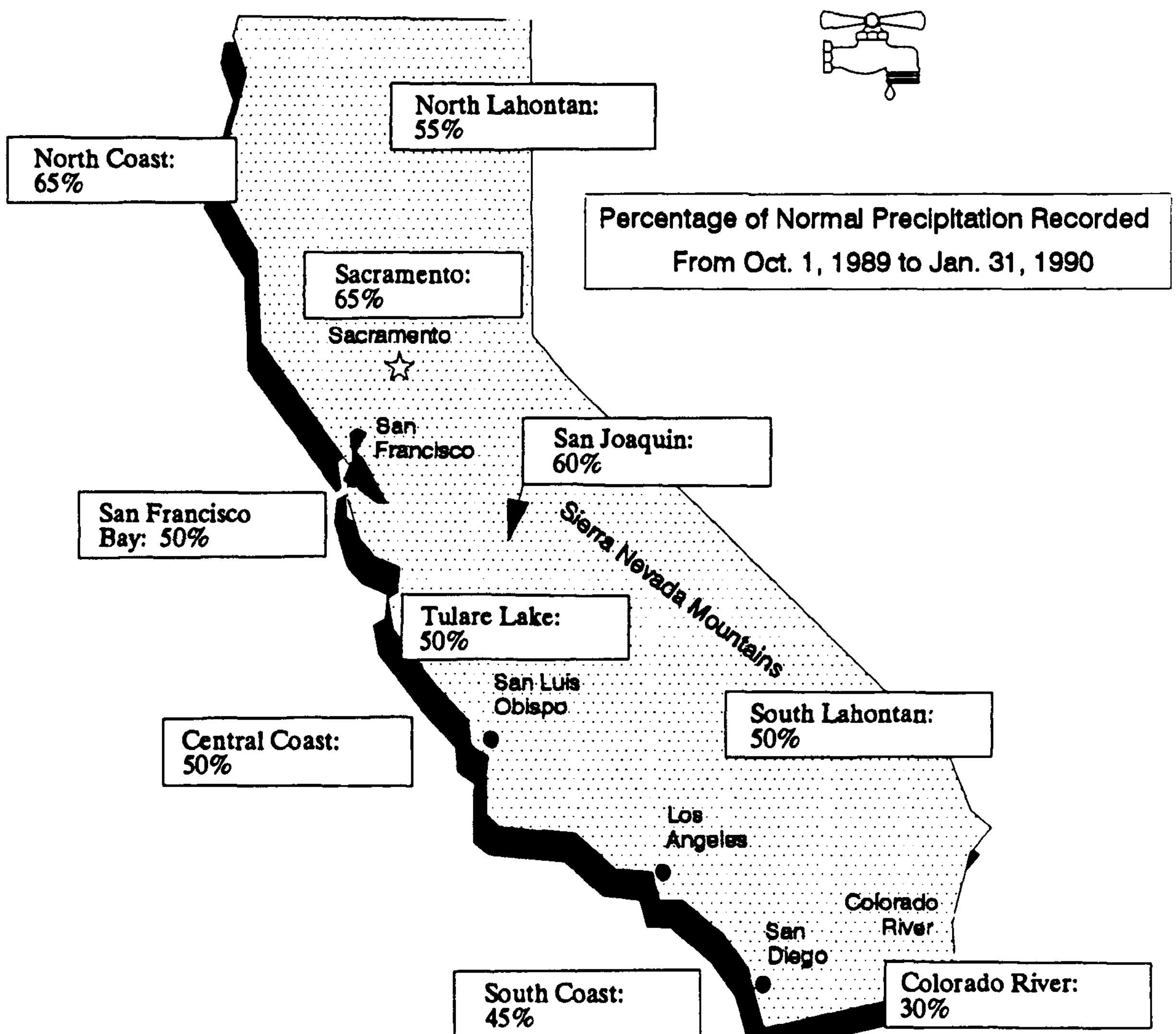
The loss of soils and vegetation cover cause other significant problems. Greater quantities of runoff would flow over an area in less time, flood peaks would be higher, and seasonal flow variation increased, while groundwater recharge would decrease. GCC could increase significantly the risk of flooding and drought in areas that are thought to be safe in today's environment. Table 6 lists possible impacts to existing waterway systems [7-17]. The list shows how water supply reservoirs, flood protection systems, hydropower reservoirs, and environmental resources can all be adversely affected by GCC.

The experience of California's water problems are very grave. Figure 22 identifies key locations in California and the percentage below their normal precipitation levels during FY 1990 [7-18]. The situation is bleak as shown on the chart, as the areas are running from 30% to 65% below normal precipitation amounts. California relies heavily on runoff from the mountains. A worse case scenario for the coming decades due to GCC would be an early melt of the snow pack. This would cause a surge of water and increased sedimentation in the dam systems. The dams would have to release large quantities of water during these surges much earlier in the year than normal. Their capacity to hold water would also decrease because of the building sedimentation problem. With each passing year the dams would hold less and less water. As spring turns to summer, the flow into the dam systems would fall below normal since most of it had melted prematurely. The population in California is continuing to increase which greatly fuels an already heated competition between cities, industry,

Table 6: Examples of first order impacts of climate change on water resources.

| | Annual runoff reduced | Runoff frequency changed - more droughts | Runoff seasonality changed - less even distribution | Sediment production increased |
|---|---|---|---|---|
| **Semi-arid areas** | | | | |
| 1. Water supply reservoirs | Proportionately larger reduced yield | Reduced yield and reliability | Reduced yield and reliability | Loss of storage reduced yield |
| 2. Flood protection | n.a. | Fewer wet years more flood protection | More wet season runoff. Could increase flood hazard | Loss of reservoir storage. River channel aggrades increased flood hazard |
| 3. Hydropower reservoirs | Reduced generation | Reduced firm load | Reduced generation and firm load | Loss of storage reduced generation |
| 4. Environmental resources | Water quality instream and downstream uses impared | Water quality impared affected significantly | Dry season water quality and instream uses impared | Water quality impared by sediment instream uses by aggradation |
| **Humid areas** | | | | |
| 1. Water supply reservoirs | Increased yield | Increased yield and reliability | Reduced yield and reliability | Loss of storage reduced yield |
| 2. Flood protection | n.a. | Flood frequency increase, river channel changes, significant increase in flood hazard | Flood frequency increases, significant increase in flood hazard | Loss of reservoir storage. Increase in flood hazard |
| 3. Hydropower reservoirs | Increased generation | Increased generation and firm load | Reduced generation and firm load | Loss of storage reduced generation |
| 4. Environmental resources | Water quality instream and downstream uses improved | Water quality instream and downstream uses improved | Minor adverse impacts | Water quality and instream uses impared by sediment |

(Source: Williams, 1989)




(Source: The Washington Post, April 8, 1990)

Figure 22: California's dwindling water supply

fisheries, agriculture, and recreation for water rights. This cycle will only get worse if left uncorrected.

It would seem that there would be an emphasis to define and solve these problems early on considering the length of time required to plan and implement such projects. However, a study by Schwarz and Dillard showed that most managers and planners have an apathetic or "wait-and-see" attitude toward this problem [7-19].

A study by the Environmental Protection Agency (EPA) on other potential scenarios that could impact California in a doubled $CO_2$ environment is shown in figure 23 [7-20]. The figure shows the results of three GCMs on temperature and precipitation. They all agree on general warming from $1^{o}$ to $5^{o}$C, but there is disagreement as to the change in precipitation. Generally, precipitation will be greater year round between the normal and warmer climates, but with most occurring in the winter. Effects of GCC are a decreased delivery of water and reduced water quality. With sea level rise, California could experience a loss of wetlands, intrusion of brackish water further inland with associated changes in marine life. Agriculture would demand more water, and have to shift to crops that are more drought resistant. Air quality would be reduced and the demand for electricity would be on the rise as well.

Water, the one basic resource that is easily taken for granted today, could become the battleground in the future. A warmer climate could have a dramatic and adverse influence on customary usage of water across the country. In the Great Plains, agriculture may have to switch from normal crops to drought resistant crops. New irrigation systems may have to be built to sustain existing farms even with these different crops due to the variability and reduced rainfall shown in figure 24. The quality of the water could be greatly tarnished as well from the chemicals used to fertilize the crops. Electricity would again be in great demand.

The southeast U.S. would likewise encounter problems with water shortages for agricultural purposes. Decreased crop yields are expected from drought stress and pestilence. As in the other two scenarios, irrigation needs will be heightened. The Southeast has an additional problem with sea level change as shown in figure 25. Higher water temperatures and rising sea level could greatly reduce fish and shellfish populations, and adversely affect current wetlands and coast lines. Problems with irrigation and water quality could further deteriorate due to intrusion of brackish water further inland.

The Great Lakes region will also encounter significant difficulties in a warmer climate as shown in figure 26. Water quality will likely become a major issue. The level of the lakes are expected to decrease due to increased evaporation. Though there will be reduced ice coverage by 1-3 months that will enhance commerce, the fall in the lake level will force ships to reduce their loads, and there will be a greater need to dredge harbors and channels. A study conducted by Environment Canada determined that the average annual costs of shipping would increase to approximately $10 million assuming shipping tonnages would remain the same [7-21]. These dredging operations

**Water Resources**

Regional warming could cause:

* decreased deliveries from Central Valley Project and State Water Project
* decreased water quality in subalpine lakes

**Wetlands and Fisheries**

Sea level rise could cause:

* gradual inundation of wetlands
* increased salinity in and size of San Francisco Bay
* shift from brackish and freshwater species to marine species

**Agriculture**

Increases in temperature and CO2 concentrations could cause:

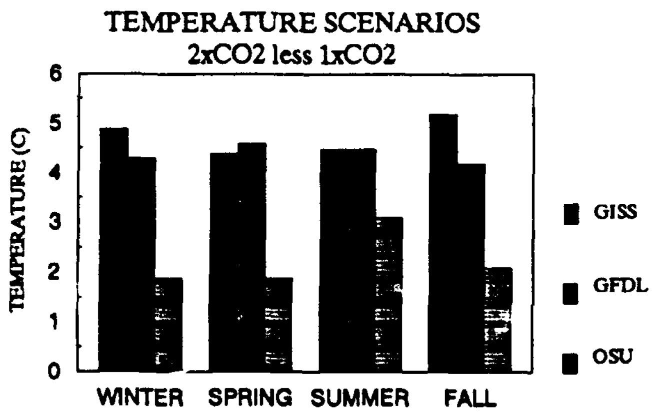
* variable crop responses
* a northward shift in agricultural
* increased irrigation demand resulting in ground water extraction and decreased water quality

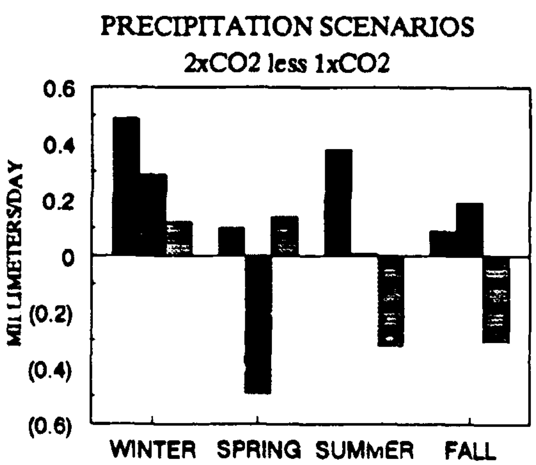
**Air Quality**

Higher temperatures would increase ambient ozone levels in Central California

**Electricity**

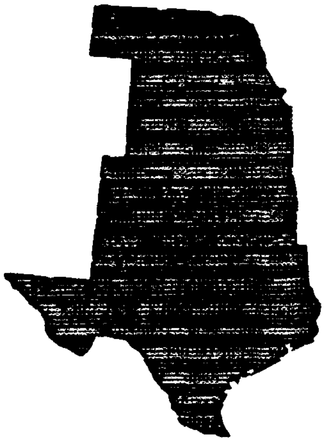
Higher temperatures could increase electricity demand




(SOURCE: Adapted from EPA 1989, Report to Congress)

Figure 23: The California scenario



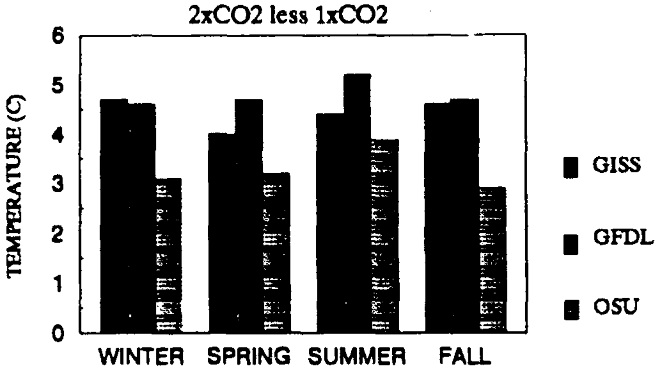
(Except Central and Southern Texas)

**Agriculture**

Higher temperatures could:

* reduce corn and wheat yields, and could have mixed effects on yields when considering both climate change and increased $CO_2$
* reduce crop acreage

TEMPERATURE SCENARIOS
2xCO2 less 1xCO2



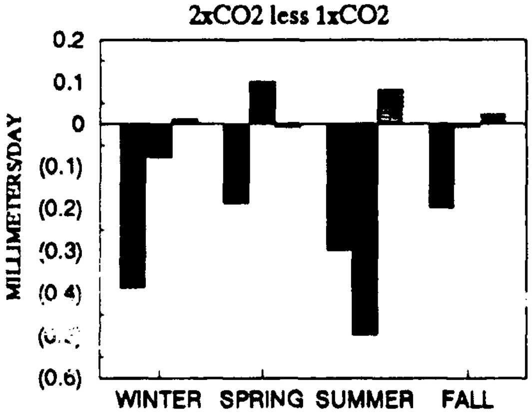

**Irrigation Demand**

Changes in agriculture are likely to result in increased irrigation demand and acreage

**Water Quality**

Changes in rainfall, runoff, pesticide loadings, erosion, and irrigation could affect water quality

PRECIPITATION SCENARIOS
2xCO2 less 1xCO2




**Electricity**

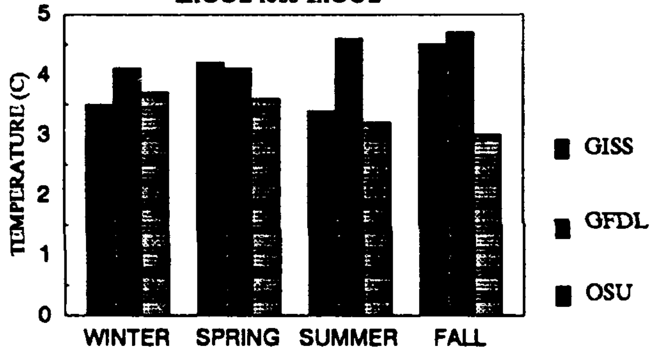
Higher temperatures could increase electricity demand

(SOURCE: Adapted from EPA 1989, Report to Congress)

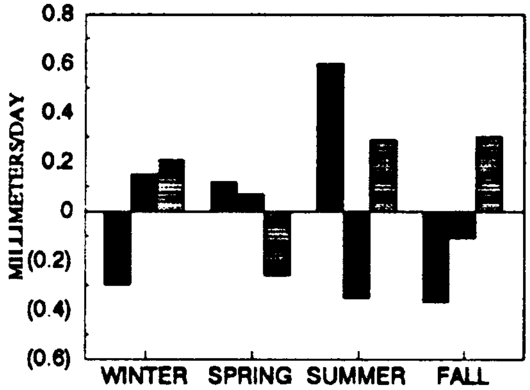
Figure 24: The Great Plains scenario

(Excluding inland areas
in Texas and Louisiana)

TEMPERATURE SCENARIOS
2xCO2 less 1xCO2




PRECIPITATION SCENARIOS
2xCO2 less 1xCO2




(SOURCE: Adapted from EPA 1989, Report to Congress)

**Agriculture**

Climate change could:

* decrease corn and soybean yields in hotter areas and could have mixed results elsewhere
* decrease in cultivated acreage
* increased need for irrigation
* increased pest infestations

**Forests**

Higher temperatures could result in:

* significant dieback of southern forests with declines evident in 30 to 80 years
* regeneration of species becoming difficult

**Water Resources**

Increased temperature and changes in precipitation could:

* produce uncertain effects for water resource availability
* affect water quality and flood risks
* lower levels in some recreational lakes

**Sea Level Rise**

Rising sea level could:

* inundate a significant proportion of the region's coastal wetlands
* flood some dry land areas
* create significant costs for protecting coastal resources

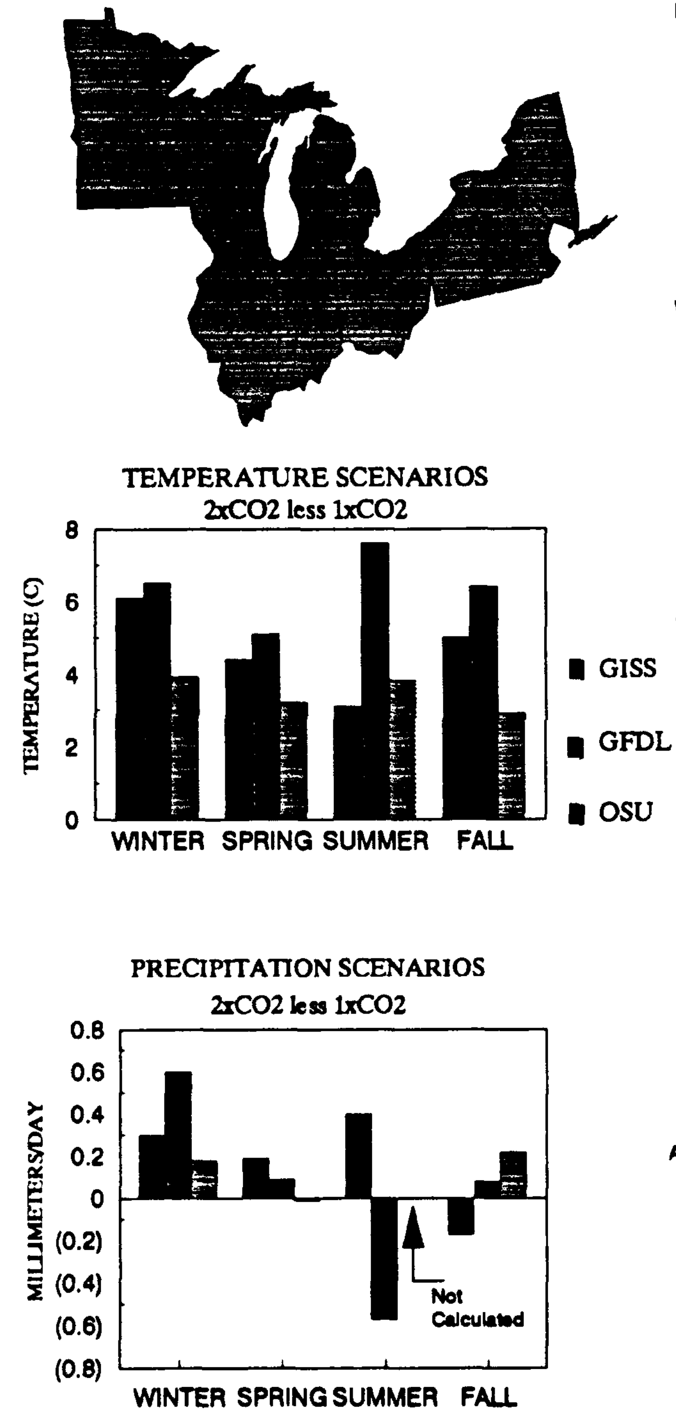
**Fisheries**

Higher water temperatures and rising sea level could reduce fish and shellfish populations

**Electricity**

Higher temperatures could increase electricity demand

Figure 25: The Southeastern U.S. scenario




(SOURCE: Adapted from EPA 1989, Report to Congress)

Lakes

Climate change could:

* cause average lake levels to fall by 0.5 to 2.5 meters
* reduce ice cover duration by 1-3 months

Adjustments maybe required, including:

* increased dredging of harbo.s and channels, or
* lower cargo capacities on ships

Water Quality

Changes in temperature and precipitation could result in:

* greater stratification in lakes and increased growth of algae, which in turn could cause lower dissolved oxygen levels in shallow areas
* an increase in pollutants resulting from more dredging

Wetlands and Fisheries

Higher temperatures could result in:

* an increase in fish habitats in fall, winter, and spring, and a decrease in summer
* accelerated growth for some fish species
* potential invasion by new species

Forests

Higher temperatures could cause:

* loss of mixed northern hardwood and oak in southern areas
* shifts of mixed northern hardwood and boreal forests in northern areas to all northern hardwood
* forest declines evident in 30 to 60 years

Agriculture

Higher temperatures could cause:

* corn and soy bean yields to increase in North, decline in Cornbelt mixed results under climate change and CO2
* acreage could expand in the North leading to increased erosion and runoff

Figure 26: The Great Lakes scenario

would pose another environmental problem, an increase in the amount of pollutants in the water.

Marine life would be adversely affected in the warming climate in the Great Lakes. Not only will they have to deal with increased pollutants from dredging, but the thermal structure of the water column in the lake will become more stratified. Algae would flourish in this situation, lowering levels of dissolved oxygen in shallow waters.

Forests again would change in a warming climate. It is expected that the diversity that now exists would diminish in favor of more hardwoods. Unlike other vegetative responses, the forests will take decades to respond to the stress associated with the warming.

In a study by Environment Canada [7-22], the impact of a warmer climate on the Great Lakes region based on the output of the GFDL and GISS GCMs was studied. Their results were quite similar to the EPA report, and are repeated in table 7.

# Sea Level Changes

Many scenarios as a result of GCC have been elaborated. One that still remains a mystery is sea level change. What was once declared to be a potential cataclysmic event for future generations has been greatly scaled back. The problem of quantifying all the factors that influence sea level changes still exists. The significance of sea level rise, however, cannot be underestimated.

Current estimates based on a $4^{o}$-$6^{o}$F warming in the middle of the next century is a rise of about 12 inches by 2050 [7-23]. The change in the projected sea level rise is due to the discovery that the ice sheet over Greenland is growing rather than shrinking which was the basis for the earlier pessimistic projections. If the entire Greenland ice sheet melted and flowed into the ocean, the sea level would rise 20 feet. If all the ice on Antarctica melted, the rise would be 230 feet. Nevertheless, the errors associated with these revised estimates of a sea level rise are as large as the projected magnitude of change, within 12 to 18 inches.

There are three main processes that influence sea level change. The processes that are sensitive to GCC are changes in ice mass on land and changes in ocean water temperature. Changes in liquid water stored on land in ground-water aquifers or surface reservoirs also have a bearing on sea level. The average rate of change in sea level the past 50 years has been 2.4 +/-0.9mm $yr^{-1}$.

Trying to explain all the factors that contribute to sea level change, and to quantify their influence on the present is difficult. To project changes based on this sketchy information is extremely difficult. Table 8 lists the estimates provided by Meier that account for the expected 0.3 m rise in sea level in the year 2050 [7-24]. Again, the margin of error for these estimates are about the same as the change itself.

Table 7: Implication of climate change for navigation and power generating in the great lakes in a doubled $CO_2$ environment

- Mean Great Lakes may be reduced 30-80 cm and mean flows in the connecting channels may be reduced by 20%,
- The frequency of low water levels (as in the 1930's and 1960's) would occur in 8 years out of 10.
- Maximum ice cover on the Lakes may decline from 72% to 0% for Lake Superior, 38% to 0% for Michigan, 65% to 0% for Huron, 90% to 50% for Erie, and 33% to 0% for Ontario, permitting an 11 month ice-free shipping season.
- Average annual costs to Canadian Great Lakes shipping companies for the four principal cargoes, iron ore, grain, coal and limestone, may increase by 30%.
- The frequency of years when shipping costs equal or exceed those of the period of low lake levels of 1963-1965 may occur in 9 years out of 10.
- For the Canadian hydro generating stations on the Great Lakes, climate change plus increased consumptive use could result in a loss of 4165 gigawatt hours of power generation.
- Warmer temperature will result in a lower demand for energy in winter and a slight increase in summer, resulting in an average annual saving of $172-204 million (Canadian 1984 dollars) for Ontario Hydro.

(Source: Environment Canada, 1987)

There are regional changes in sea level as well. Maul and Hanson [7-25] studied sea level records for the U.S. and found that the general rise in sea level is about 0.2-0.3 cm $yr^{-1}$, except along the Louisiana to Texas coast where the rise is 3 to 5 times greater than the U.S. average. Their study found that sea level fell prior to about 1931, then rose rapidly into the 1950s. Thereafter it rose at a reduced rate. There are several regional factors that could influence changes in sea level such as glacial rebound, tectonic uplift and subsidence, and restoring flows of sediment along coastal regions.

There are numerous repercussions associated with a 0.3 m rise in sea level. The EPA report identified many such factors [7-26]. Destruction of coastal wetlands, in-

Table 8: Factors that directly relate to changing global sea levels in the year 2050

| | |
|---|---|
| Thermal expansion | 0.2 +/-0.1 m $yr^{-1}$ |
| Ground water depletion | 0.2 +/-0.3 m $yr^{-1}$ |
| Small glaciers ice caps | 0.16 +/-0.14 m $yr^{-1}$ |
| Greenland Ice Sheet | 0.08 +/-0.12 m $yr^{-1}$ |
| Antarctic Ice Sheet | -0.3 +/-0.2 m $yr^{-1}$ |
| Total rise | 0.34 +/-0.46 m $yr^{-1}$ |

(Source: Meier, 1990)

undation and erosion of beaches and barrier islands, flooding, and salt water intrusion are expected to occur with a rise in sea level, not to mention disruptions in marine life and the industries it supports.

Flooding, in particular, could be a significant problem with coastal areas that have experienced most of the population growth in this country. Higher sea levels would provide a higher base for storm surges. A 1-meter sea level rise would enable a 15 year storm to flood many areas that today are flooded by 100 year storms. Beach erosion would increase, coastal drainage would decrease, and a rise in water tables would result from a rise in sea level.

The southeastern U.S. would bear the brunt of all the adversities associated with rising sea levels. It was reported that for approximately every foot sea level rises, Florida Bay moves 10 miles inward [7-27]. The EPA also reported the Southeast would suffer about 90% of the land loss and 66 % of the shore protection costs [7-28]. Table 9 lists the percentage change in wetlands for a 1 meter rise in sea level for the U.S. [7-29]. An interesting point about the table is that as more protection measures are put in place to protect drylands and structures, the more wetlands will be lost. The erection of bulkheads and levees to protect drylands and structures would prevent the formation of new wetlands inland.

The above simulations are based on GCMs that have made many assumptions and have simple permutations to describe very complex processes in the Earth system. As shown in this chapter, they do provide useful information to assess impacts from climate change, but the results have to be tempered with the knowledge that there could be wide variance in the results due to the limitations of the GCMs.

Table 9 : Wetland loss due to a one meter rise in sea level.

| [illegible] | [illegible] | [illegible] (% loss) | [illegible] | No protection (% loss) |
|---|---|---|---|---|
| Northeast | 600 | 16 | 10 | 2 |
| Mid-Atlantic | 746 | 70 | 46 | 38 |
| South Atlantic | 3,813 | 64 | 44 | 39 |
| South and West Florida | 1,869 | 44 | 8 | 7 |
| Louisiana | 4,835 | 77 | 77 | 77 |
| Other Gulf | 1,218 | 85 | 76 | 75 |
| West | 64 | 56 | ? | ? |
| | | | | |
| United States | 13,145 | 50-82 | 29-69 | 26-66 |

(Source: Environmental Protection Agency, 1989)

# U.S. COMMITMENT AND BUDGET OUTLINE FOR 1992

Global climate change is a topic of great concern throughout much of the Federal Government. In response to widening interest about the world's changing environment, the Bush Administration has proposed an aggressive budget plan to Congress for FY 1992 to research GCC. The proposed budget for the U.S. Global Change Research Program is 24 percent more than the FY 1991 budget. Though much has been reported recently of disputes within the Administration over climate change, the essence of these debates has been over policy. There is agreement on the need to have a comprehensive study on global climate change, which has resulted in strong support to increase funding for research.

The Global Change Research Program (GCRP) is the umbrella that all federally funded research on climate change falls under. The committee responsible for overseeing the GCRP is the Committee on Earth and Environmental Sciences (CEES). This committee was formed by action of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). It is chaired by the Director of the Office of Science and Technology Policy in the Executive Office of the President.

The CEES was formed to increase the general effectiveness and productivity of the Federal R&D efforts that are directed toward an understanding of Earth as a global system. This committee publishes a report each year called the U.S. Global Change Research Program that contains the proposed budget for the following fiscal year, and accompanies the President's fiscal year budget. This report is very thorough and much of the contents from the 1989 [8-1], 1990 [8-2], and 1991 [8-3] issues are repeated here. This will present a clear view of how the research effort on global climate change is being directed and funded.

The foundation for the GCRP is the belief that effective strategies to address environmental issues are built only on sound scientific information. Impacts based on newly gained or affirmed scientific knowledge can then be assessed, and policies properly formulated. Linking the U.S. scientific program on global climate change to the policy process requires much effort and money in research. The benefits from such an approach are many. Decision makers car decide what impacts deserve their immediate concern, and to develop long-term strategies from this method. The information gained from GCRP also will provide the decision makers the basis to discriminate climate change into two groups, natural variability and human induced change. A subset of this data will be the magnitude and timing of these changes. These separations will aid in the formulation of policy needed to address impacts from global climate change. It also provides the means to balance regulatory needs with economic and social development, and enable research efforts to focus on those parts that human interventions will have the greatest impact.

The CEES is the bridge that unites scientific research, impact assessment, and policy making. They are the hub of America's endeavor in the study and understanding of global climate change. The goal of the CEES is:

> To establish the scientific basis for national and international policy-making relating to the natural and human-induced changes in the global Earth system.

The three objectives they have to meet this goal are:

- To establish an integrated, comprehensive long-term program of documenting the Earth system on the global scale.
- To conduct a program of focused studies to improve our understanding of the physical, geological, biological, and social processes that influence Earth system processes and trends on global and regional scales.
- To develop integrated conceptual and predictive Earth system models.

Several Federal Departments and Agencies are represented on the CEES and have an active role in the United States Global Change Research Program (USGCRP). They are:

| | |
|---|---|
| (Focus Group) | |
| Department of Agriculture | (USDA) |
| Department of Commerce | (DOC) |
| Department of Energy | (DOE) |
| Department of Interior | (DOI) |
| National Science Foundation | (NSF) |
| Environmental Protection Agency | (EPA) |
| National Aeronautics & Space Administration | (NASA) |
| (Guidance Group) | |
| Council of Environmental Quality | (CEQ) |
| Department of State | (DOS) |
| Department of Transportation | (DOT) |
| Office of Management and Budget | (OMB) |
| Office of Science and Technology Policy | (OSTP) |

The above list is divided into two groups, the Focused and Guidance Groups. All the participants in the CEES have specific roles in the GCRP, which are determined by the group they are in. The Focused Group is comprised of agencies whose budget initiatives relate primarily to global climate change research. The Guidance Group contributes to the general guidance of the program. The guidance group is instrumental for the coordination and linking of the USGCRP with national and international policy on global change. The White House Office of Policy Development also participates in the Guidance Group.

There is another group of agencies and departments that are not explicitly involved in the GCRP, but their research efforts support many science elements in the program. This is the Contributing group, whose programs were initiated for reasons other than the focused goal. The Department of Defense has many of these types of programs, and some departments involved in this effort are the Office of Naval Research, Oceanographer of the Navy, and the U.S. Army Corps of Engineers.

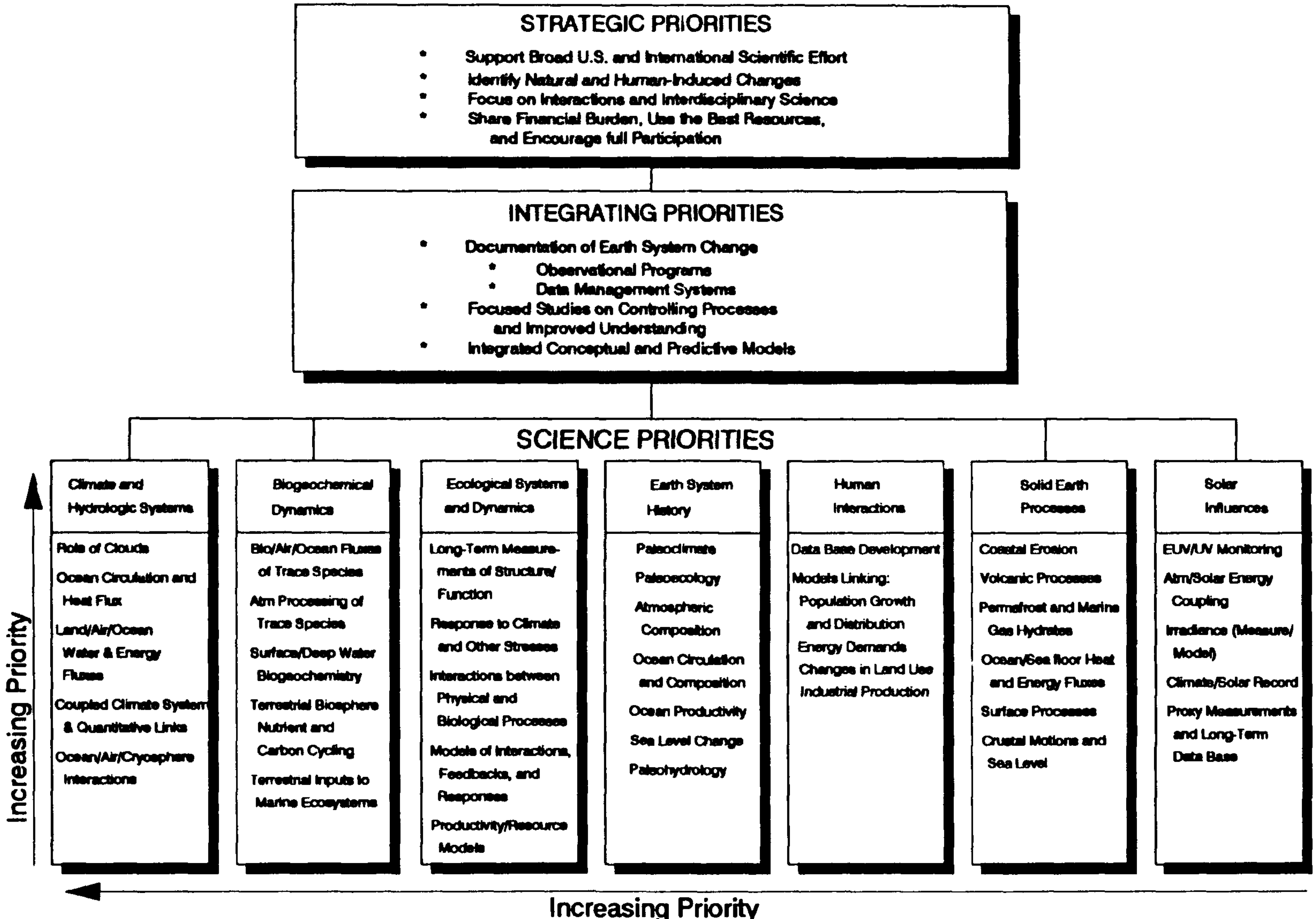
To simplify the budget process, the CEES categorized the scientific research effort in the GCRP into seven major categories, and set priorities.

The seven categories for the GCRP in decreasing priority are:

- Climate and hydrologic systems
- Biogeochemical dynamics
- Ecological systems and dynamics
- Earth system history
- Human interactions
- Solid Earth processes
- Solar influences

Within each category is a prioritized list of related research elements. The list of the science priorities, strategic priorities and integrating priorities are diagramed in figure 27.

The highest priority has been given toward the understanding of the climate and hydrologic systems. This and all its related science elements shown in figure 27 constitute the most serious questions we have today about global climate change. Once the understanding of these issues rises above the mire of serious doubt, then the simplistic parameters for these elements made in current general circulation models (GCMs) can be properly formulated. A direct result of improved GCMs will be more realistic scenarios about future climate both in the near term and long term. The improvements in the GCMs will have an effect on the output of other models for diverse environmental concerns. The EPA, Forest Service, and other agencies have coupled their meso and micro scale models to the GCMs. By this technique they hope to find what stresses will be imposed on the environment by expected future climate change. It is thought that




(Source: The Committee on Earth Sciences, 1990)

Figure 27: U.S. Global Change Research Program priority framework.

coupling the higher resolution models to the GCM's will provide more realistic model output. The improved model output also will trickle down to the policy issues. Policy will be formulated on improved information, and therefore bring greater balance between the economic, social, and environmental forces.

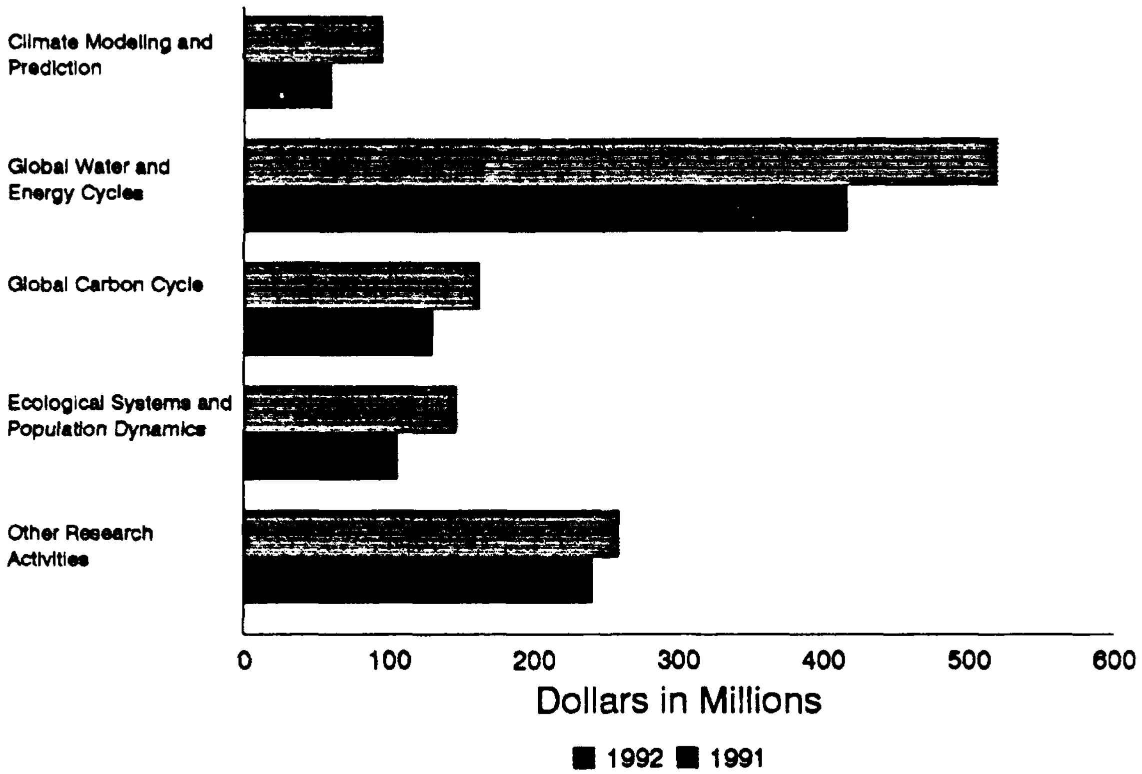
Besides the prioritization of research efforts, the CEES has tried to remain in concert with research efforts of other international governing bodies. To this extent, the CEES has relied on the Intergovernmental Panel on Climate Change (IPCC) and its findings on Scientific and Impacts Assessments. From this basis the CEES formed four integrating themes. This will focus the collective efforts of the U.S. government and academic scientists in collaboration with scientists from other governments. This effort is to ensure that this is a truly international cooperative effort that should provide a broader understanding of global climate change. The four integrating themes for FY 1992 are:

- **Climate Modeling and Prediction**: To develop an improved predictive capability of the Earth as a coupled system with enhanced regional resolution, with initial priority given to the climate system.
- **Global Water and Energy Cycles**: To improve the understanding of the water (precipitation, evaporation evapotranspiration, soak moisture, ice quantity, type and movement) and energy cycles (warming/cooling, radiative balance, solar variability, latent heat), by focusing on the:
  - » **Role of Clouds**: Primarily the role of water vapor and cloud formation, dissipation and radiative properties;
  - » **Role of the Oceans**: The exchange of energy and mass (e.g., water) between the ocean, sea ice, and the atmosphere; between the upper layers of the ocean and the deep ocean; and transport within the ocean;
  - » **Role of Terrestrial Ecosystems**: The exchange of energy and water balance between the atmosphere and the surface of managed and natural terrestrial ecosystems and soils; and
  - » **Change in Sea Level**: That is an integrated Earth system response to the changing climate conditions, by examining the role of polar ice sheets and thermal expansion of the oceans and melting land glaciers.
- **Global Carbon Cycle**: To improve the understanding of the carbon cycle by quantifying the natural and anthropogenic terrestrial and oceanic sources and sinks of key carbon compounds (e.g., carbon dioxide, methane and ozone precursors such as carbon monoxide and the non-methane hydrocarbons). This includes their chemical reactions in the atmosphere and oceans; the chemical, biological and physical processes that control their fluxes; how these fluxes may be influenced by climate change; and how

changes in greenhouse gas abundances affect the magnitude and rate of change.

- **Ecological Systems and Population Dynamics**: To improve the capacity to assess the effects of global rate of change at regional scales. Specifically, to improve understanding of the responses of intensively managed and natural oceanic and terrestrial ecosystems to global change by focusing scientific research on:
  - » species composition of ecosystems;
  - » distribution and extent of ecosystems; and
  - » productivity of ecosystems.

Figure 28 shows the amount of the budgeted focused United States Global Change Research Program (USGCRP) that falls under the preview of the integrating themes. Research in Global Water and Energy has most of the monies being spent in the GCRP. The least amount of monies being allocated to Climate Modeling and Prediction. It should be noted that there is a projected increase in funding for all catego-




(Source: The Committee on Earth Sciences, 1991)

Figure 28: FY 91-92 USGCRP focused budget by integrating theme.

ries. This may be a result of heightened awareness and concern of the impacts of climate change.

The focused budget for the USGCRP that is being presented to Congress for FY 1992 is shown in table 10. This table breaks down the focused budget by agency, program, and scientific objective. Table 11 similarly lists the budget for contributory programs. These tables show a proposed FY 1992 budget for focused programs of $1.186 billion, a $231.8 million or 24 percent increase over the FY 1991 level. The combined budget for focused and contributing research is $2.416 billion.

Several figures are provided to show graphically the differences in allocation provided to each focused program, agency, scientific objective for FY 1991-1992, and ground-and space-based programs for FY 1990 and FY 1991.

Figure 29 shows most of the money for focused programs being allocated toward the research of climate and hydrology. These two categories, with their sub elements shown in figure 27 are crucial to the development of more reliable GCM's, both in the global and regional scales. Biogeochemical dynamics and ecological systems and dynamics provide a strong second and third place in dollar allocation.

The scientific objective of understanding is shown in figure 30 to have the greatest research dollars allocated to it. There are many questions about the Earth System, and understanding the processes and interactions of its changes are crucial to formulating policy. Global climate change is just a subset of the Earth System, but its impact is pervasive over many other subsets in the Earth System.

Data management is shown in figure 30 to be third in total dollar allocation, but its importance is not commensurately diminished. The largest failure of many past research efforts on climate and earth monitoring programs has been the inefficient use and storage of data. It was reported that at the Jet Propulsion Laboratory (JPL) in Pasadena there are 30 years of space flight data that have not been cataloged and are generally unusable. The data are on about 200,000 space mission tapes, wound on 12-inch reels, and stored in airtight canisters. The problem JPL faces is little to no documentation on how to retrieve the data from the tapes Some tapes require special hardware that are no longer in use or manufactured. Some information contained on these tapes are on global climate change, deforestation, and the ozone layer. To underscore this problem, the U.S. Geological Survey found more than 3,000 images from the Viking mission to Mars in the late 1970's that were not processed from the master data record [8-4]. Data management for the GCRP is a very important issue. The use and availability of the data to the scientific community will decide the level of success for the GCRP.

The most eye catching part of the budget is the amount allocated to NASA shown in figure 31. NASA accounts for the lions share of the budget over any of the other six agencies in the focus category. NASA's 'Mission to Planet Earth program,' which will provide total surveillance of the earth from space, is being funded through the

Table 10: FY 1991-1992 U.S. Global Change Research Program focused budget.

| Focused Program | Total Budget | | Climate & Hydrologic Systems | | Biogeo-chemical Dynamics | | Ecological Systems and Dynamics | | Earth System History | | Human Interactions | | Solid Earth Processes | | Solar Influences | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 |
| Agency Totals | 953.7 | 1,185.5 | 450.7 | 580.1 | 249.1 | 280.9 | 140.0 | 188.4 | 18.2 | 21.4 | 28.3 | 31.0 | 53.6 | 66.5 | 13.8 | 17.2 |
| DOC/ NOAA | 47.0 | 78.0 | 37.3 | 61.0 | 7.4 | 10.4 | 0.6 | 2.4 | 1.7 | 2.2 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 0.0 | 6.3 | 0.0 | 3.8 | 0.0 | 0.9 | 0.0 | 1.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| DOE | 65.5 | 77.0 | 44.2 | 54.0 | 11.0 | 13.0 | 7.4 | 7.3 | 0.0 | 0.0 | 3.0 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOI | 36.6 | 46.4 | 12.7 | 14.2 | 3.0 | 3.0 | 7.2 | 12.7 | 7.5 | 9.1 | 1.6 | 2.1 | 4.6 | 5.3 | 0.0 | 0.0 |
| EPA | 21.8 | 26.0 | 0.0 | 0.0 | 7.2 | 9.3 | 6.3 | 7.4 | 0.0 | 0.0 | 8.3 | 9.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 651.6 | 772.6 | 326.3 | 399.8 | 185.7 | 196.1 | 81.8 | 113.1 | 0.0 | 0.0 | 10.2 | 1.8 | 38.3 | 50.2 | 9.3 | 11.6 |
| NSF | 87.1 | 118.5 | 28.1 | 41.8 | 22.4 | 29.9 | 12.5 | 17.9 | 6.2 | 6.8 | 3.6 | 6.8 | 9.9 | 9.8 | 4.4 | 5.5 |
| SMITH-SONIAN | 5.4 | 7.5 | 0.0 | 0.0 | 0.2 | 0.2 | 2.8 | 4.3 | 1.0 | 1.2 | 0.5 | 0.8 | 0.8 | 0.9 | 0.1 | 0.1 |
| USDA | 38.6 | 53.2 | 2.1 | 5.5 | 12.2 | 18.1 | 21.4 | 22.3 | 1.8 | 1.8 | 1.1 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 |

(Dollars in Millions)

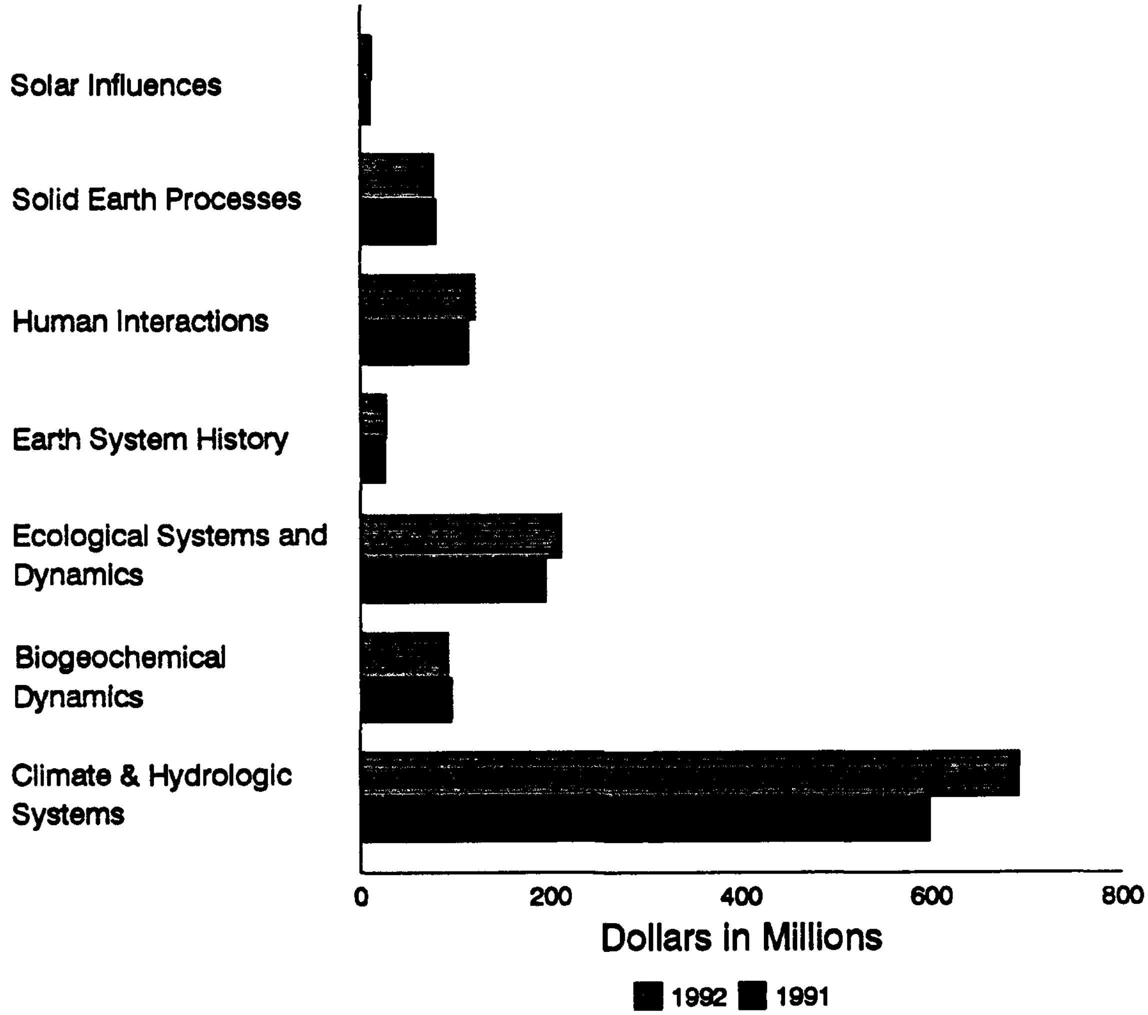
(Source: The Committee on Earth Sciences, 1991.)

Table 11: FY 1991-1992 budget of Contributory Programs to the U.S. Global Change Research Program.

| Focused Program | Total Budget | | Climate & Hydrologic Systems | | Biogeo-chemical Dynamics | | Ecological Systems and Dynamics | | Earth System History | | Human Interactions | | Solid Earth Processes | | Solar Influences | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 |
| Agency Totals | 1,120.5 | 1,231.0 | 598.9 | 691.4 | 95.6 | 91.7 | 195.5 | 211.8 | 25.7 | 26.9 | 114.2 | 121.5 | 79.8 | 76.2 | 10.8 | 11.7 |
| DOC/ NOAA | 467.7 | 563.2 | 410.1 | 506.9 | 22.7 | 22.8 | 10.3 | 8.9 | 0.1 | 0.1 | 3.9 | 3.9 | 19.7 | 19.7 | 0.9 | 0.9 |
| DOD | 31.0 | 28.9 | 22.1 | 22.7 | 1.1 | 1.1 | 6.0 | 3.9 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 1.2 | 0.0 | 0.0 |
| DOE | 40.4 | 42.3 | 0.0 | 0.0 | 24.7 | 25.1 | 7.0 | 6.5 | 0.0 | 0.0 | 0.0 | 2.0 | 7.7 | 7.7 | 1.0 | 1.0 |
| DOI | 253.3 | 252.9 | 105.4 | 97.6 | 3.4 | 3.4 | 57.9 | 60.4 | 0.3 | 0.3 | 78.3 | 83.2 | 6.3 | 6.3 | 1.7 | 1.7 |
| EPA | 46.2 | 48.2 | 7.2 | 5.2 | 1.0 | 1.0 | 38.0 | 42.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 25.3 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 25.3 | 20.0 | 0.0 | 0.0 |
| NSF | 132.5 | 144.4 | 47.2 | 50.3 | 26.6 | 27.1 | 20.8 | 25.3 | 24.3 | 25.0 | 4.9 | 5.1 | 3.6 | 5.6 | 5.1 | 6.0 |
| SMITH-SONIAN | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USDA | 124.1 | 131.1 | 6.9 | 8.7 | 16.1 | 11.2 | 55.5 | 64.8 | 1.0 | 1.3 | 27.1 | 27.3 | 15.4 | 15.7 | 2.1 | 2.1 |

(Dollars in Millions)

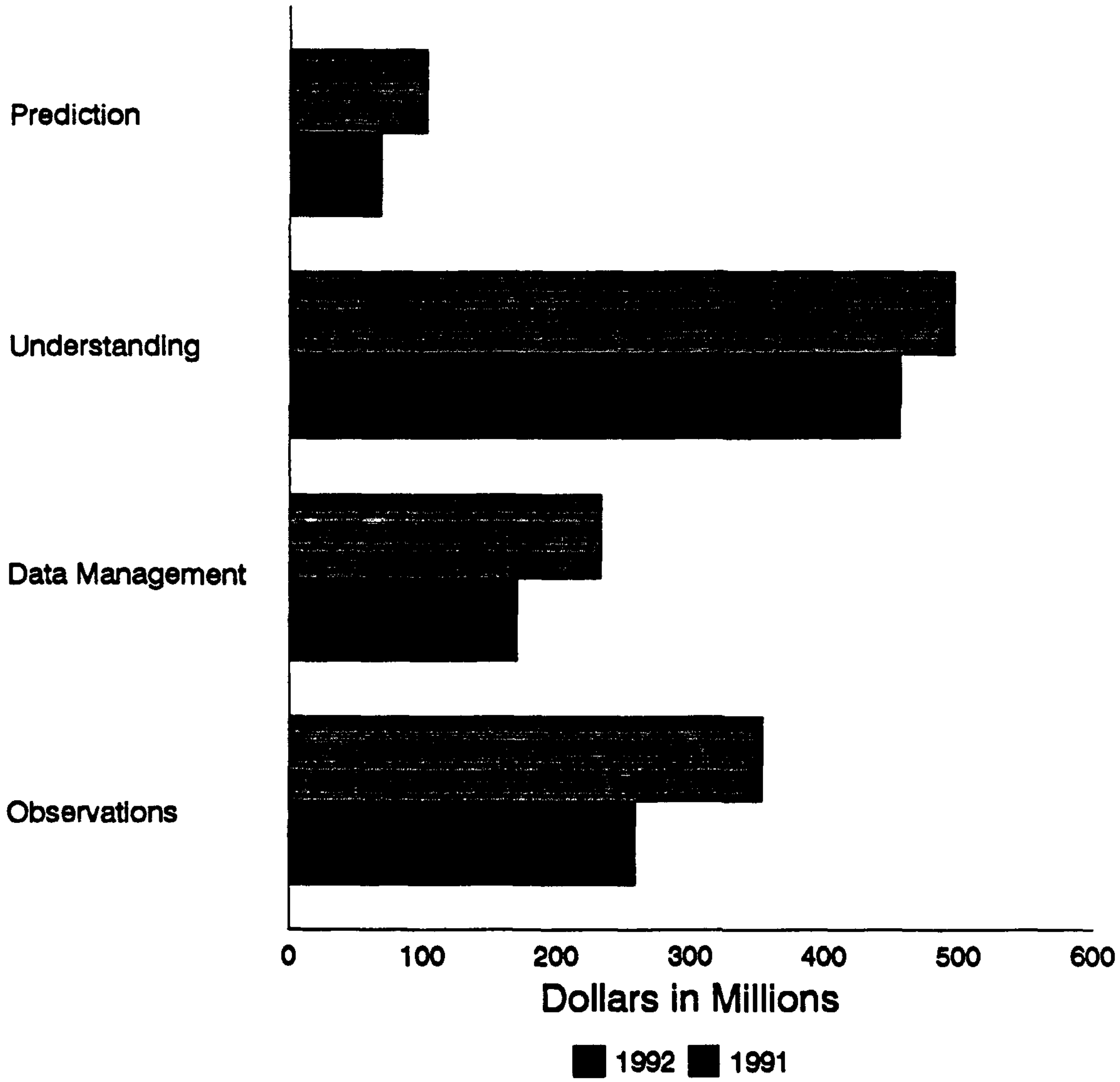
(Source: The Committee on Earth Sciences, 1991.)




(Source: The Committee on Earth Sciences, 1991)

Figure 29: FY 91-92 USGCRP focused budget by science element.

GCRP. Specialized polar orbital satellites (earth probes), two series of large polar orbiting platforms (Earth Observing System (EOS) satellites), and geostationary satellites will form the necessary network to monitor Earth constantly. France and Japan, as active participants in this program, plan to build and launch their own polar orbital and geosynchronous satellites. The U.S. in turn will build and launch four earth probes, three EOS satellites, three geosynchronous satellites, and load special monitoring sensors on the space station. The earth probes will be designed to observe specific processes in the Earth's climate and biosphere. EOS satellites are much larger, more complex, and are designed to monitor many types of processes. The program 'Mission to Planet Earth' will take most of the 1990's to be fully implemented, and the data that is ex-

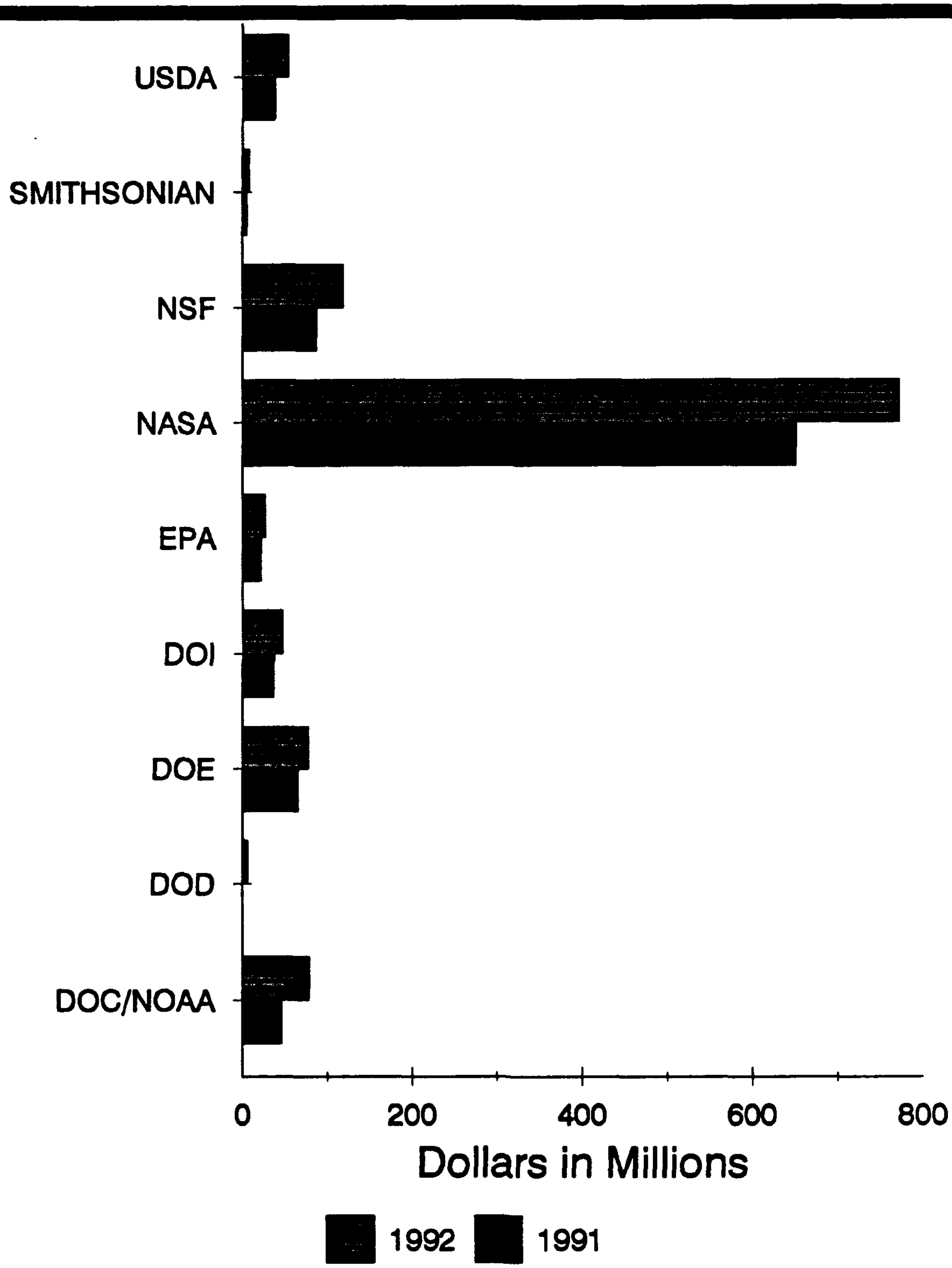



(Source: *The Committee on Earth Sciences*, 1991)

Figure 30: FY 91-92 USGCRP focused budget by scientific objective.

pected to be generated from this program in one day will exceed the amount of data generated in the entire previous history of the space program. Table 12 lists the tentative launch schedule.

NASA is ensuring that there is adequate ground-based systems to accommodate the vast amount of data streams that will be sent from the satellites. Figure 32 exemplifies how the budget is nearly divided equally between ground-based and




(Source: The Committee on Earth Sciences, 1991)

Figure 31: FY 91-92 USGCRP focused budget.

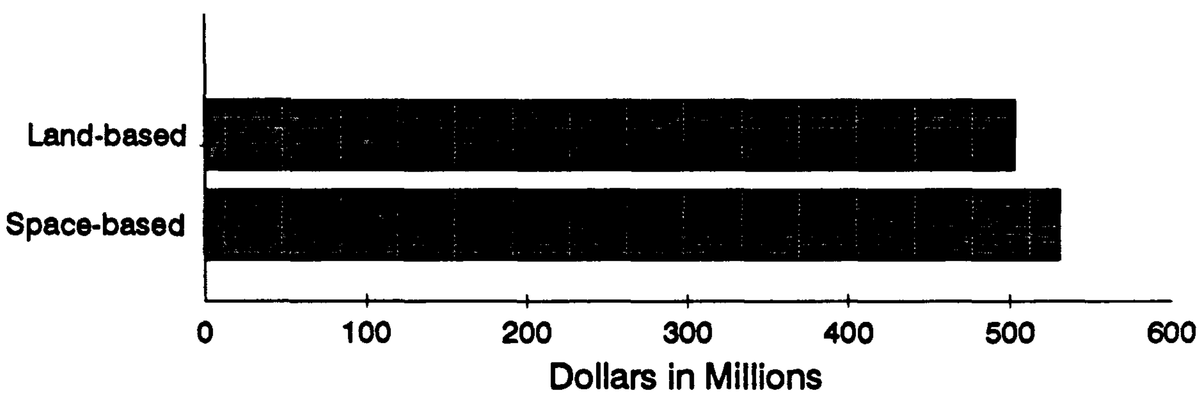
Table 12: Mission to Planet Earth tentative launch schedule.

| | |
|---|---|
| Early 1993 | Earth Probe: Sea-Viewing Wide-Field Sensor: Measures ocean color related to phytoplankton. |
| Mid-1993 | Earth Probe: Total Ozone mapping Spectrometer: Measures atmospheric ozone. |
| Mid-1995 | Earth Probe: NASA Scatterometer: Measures ocean winds. |
| Early 1996 | Earth Probe: Tropical Rainfall Measuring Mission. |
| Early 1998 | EOS-A: Measures interaction of Earth surface and atmosphere. |
| Mid 1999 | EOS-Synthetic Aperture Radar: |
| Mid-2000 | EOS-B: Measures atmospheric chemistry and ocean circulation. |

(Source: American Meteorological Society Newsletter, May 1990)

space-based systems for FY 91. The data in the FY 92 USGCRP report was not broken out to show any trends in this category.

What has been proposed by NASA [8-5] to meet the challenges in the future space exploration of Earth is the establishment of the 'EOS Scientific Research Program', the 'EOS Data and Information System (EOSDIS)', and the 'EOS Observations,' which are all subsets of the overall EOS.




(Source: The Committee on Earth Sciences, 1990)

Figure 32: FY 91-92 USGCRP focused budget by ground- and space-based progams.

The EOS Scientific Research Program falls under the coordinating efforts of the USGCRP, as well as with the International Geosphere-Biosphere Program (IGBP) and the World Climate Research Program (WCRP). The current EOS research focus is on :

- Use of existing satellite data
- Preparation for use of new types of data expected from satellite missions preceding EOS and from new aircraft instruments providing a preview of EOS capabilities
- Determination of detailed requirements for future observations
- Development of numerical models that can assimilate or help interpret current and future data sets.

The EOSDIS is being designed to give supporting EOS researchers access to data almost on demand. There are plans to establish nodes, or distribution centers, of data around the world. Each node is planned to be the manager of a unique set of data. Consequently, there will need to be a tremendous amount of international cooperation to make this system work. As reported by NASA in their EOS Research Handbook, EOSDIS will evolve in time. Problems will be encountered in this evolving process as with any program. However, it is hoped that the program's robustness and the level of international cooperation is high enough to allow this change to occur at a rate that will minimize the aberration of data flow to EOS researchers.

The EOS Observatories are the actual space platforms that will carry the sensors to monitor Earth's environment. The EOSDIS is the mechanism by which the data is relayed to EOS researchers in the most expeditious manner. Some of the environmental variables that will be monitored by these platforms are:

- Cloud properties
- Energy exchange between Earth and space
- Surface temperature
- Structure, composition, and dynamics of the atmosphere, winds, lightning, and precipitation
- Accumulation and ablation of snow
- Biological activity on land and in near-surface waters
- Circulation of the oceans
- Exchange of energy, momentum, and gases between the Earth's surface and atmosphere
- Structure and motion of sea ice; growth, melting, and flow rates of glaciers
- Mineral composition of exposed soils and rocks

- Changes in stress and surface elevation around geologic faults
- Input of solar radiation and energetic particles to the Earth.

The scientific research program, data information system and observatories that are being setup in support of EOS is an ambitious attempt by NASA to lead the world's collective effort in climate change research. Their stated goal is to advance the understanding of the entire Earth system on the global scale. To accomplish this enormous task they have planned to quantify change in the Earths system by maintaining a continuous observation network based on low Earth orbiting satellites for a minimum of 15 years. NASA is not the sole agency to conduct and manage this effort. Europe, Japan, and Canada have a direct role, while Brazil and Australia are helping to fund some EOS programs. The following eight primary EOS mission requirements adequately sum up the EOS effort:

- Provide long-term (15-year) observing capability
- Obtain at least one decade of overlapping, calibrated data from the full suite of EOS observatories providing long-term, simultaneous observations of phenomena on local, regional, and global scales
- Globally characterize the highly variable aspects of the Earth system every 1 to 3 days
- Make all EOS data and derived data products readily available in a timely manner to all approved users, with no preference given to EOS investigators
- Support the communication and exchange of research findings that result from use of EOS data or are produced by EOS investigations
- Maintain continuity in essential global change measurements of existing and planned missions
- For instruments having the potential to fly on multiple spacecraft, use instrument interfaces that are compatible with the European Space Agency (ESA) polar platforms and future NOAA optional satellites
- Support the overall USGCRP.

The Committee on Earth Sciences is the part of the administration that oversees, coordinates, and directs the total effort in the Global Change Research Program. Through their effort and support from the Bush administration, there is now set in place for Congressional approval the funds needed to expand the effort in global climate research. NASA has been given the majority of research dollars to put in place all the components to aid in the understanding of the Earth system through the EOS. EOS is a coordinated international effort, though NASA is taking the lead on this.

# NATIONAL AND INTERNATIONAL CONSEQUENCES FROM GLOBAL CLIMATE CHANGE

On a national scale let us look at the changing areas of responsibility within our own government. The relationships between the Corps of Engineers (COE) and the Environmental Protection Agency (EPA), the State Department, Department of Commerce (DOC), and the Department of the Army (DA), among others, may change with global warming. The subtle changes in climate averages will be the silent, steady force that changes some of these relationships; while sudden dramatic swings in extreme weather conditions will be the harsh erratic force that abruptly changes them. This is the area where some advance planning can possibly minimize the abrasive actions accomplished on the spur of the moment under the glare of national publicity. The U.S. recently swung from the coldest December on record, through the second warmest January and February on record, into a record heat spell in March that is immediately followed by a 2 to 4 inch snowstorm in several locations; we are provided with opportunities to watch and learn as the ecosystem slowly adapts to the change in climate. The COE in its mandate under the Army Regulation 10-5 (Organization and Functions, Department of the Army), may come under increasing pressure to protect and service Federal and Private buildings and lands. As a result, COE may need to focus more of its *efforts on the protection* and management services of our nation's natural resources as climate undergoes measureable changes. The problem of serious beach errosion in Florida may become more of the norm instead of the exception as the probability of severe storms increases with global warming [9-1].

As a COE laboratory, ETL may find itself in the field of hazardous waste containment and disposal. As watersheds change, the demands for keeping the main channels on the Hudson, or the Tombigbee-Alabama, or the Missouri-Mississippi, or the Columbia complexes (to name a few) will most likely increase. Increased dredging operations will eventually bring up large volumes of hazardous silt. In anticipation of this problem, COE could assign ETL the lead role to develop and formulate active work relations with other Corps Labs to identify geographic areas of greatest concern and the hazardous material involved. Further work could also ensue with the EPA and other cognizant agencies to refine current guidelines to better manage the physical handling and disposing of the dredged material.

There are many chemical time bombs that are contained in the silt and are slowly ticking away until the "proper" severe storm or earthquake brings them front and center to the public consciousness. Such locations include Puget Sound, the Galveston to New Orleans delta region, the Chesapeake Bay area, the Delaware River-Delaware Bay area, and the Hudson River-Upper New York Bay area. A study of core samples taken from each region may go far in determining potential areas of concern before river channels change due to storm surge problems; or they change due to loss of river volume as watersheds enter a drier climate zone.

ETL's scope of activities could easily change with respect to the changing role COE will have with DOC and the U.S. Forest Service. The two areas of immediate concern would be fisheries and forestry. As global warming induces climate change, water levels, volumes, clarity, salinity levels, PH ranges, and temperatures will all gradually change. As the COE attempts to adjust its water management practices, the general public may perceive the resultant demise of the fishing industry as the fault of COE and not the fault of climate change. As a result, COE could be faced with endless environmental litigations. Again, ETL could be assigned a lead role by COE to work with other Corps labs to help resolve these issues and provide the forensic evidence needed to support the COE's policies.

The same arguments can be used in the area of our nation's forests. As global warming gradually causes changes in this Nation's climate, whether the warming of the Mid-West and the Northeast, or the cooling of the Southeast, it will cause changes in our "normal" plant ecosystems. Forestry experts have already noted that the Douglas Fir is rapidly dying out and retreating to isolated mountaintop islands throughout the Appalachian chain. A few more above average summers and this type of tree simply won't exist in its old, normal range. Another example of changing climate altering background databases is the migration of the Jack Pine. It is very sensitive to warming trends. This tree could easily disappear from the State of Michigan over the next fifty years. The normal procession of forests from Oaks, to White Pines, to Black Spruce will be accelerated as climate change continues unabated [9-2]. The COE may want to develop new policies and direct R&D efforts to mitigate such changes. ETL could, as well, update existing background databases for tactical background scenarios; and could gather new remote sensing data in future database developments.

Another area of concern will be this Nation's limited but valuable water resources. Various water management programs will be strained to keep inland water commerce paths open. COE may become embroiled in litigations with respect to water usage. The future will hold an ever increasing demand from agricultural, environmental, and civil groups for a water resource that may not increase at the same rate as their total demand. The recent drought in California, their second longest sustained drought, will prove to be a landmark case study of the clash of modern lifestyles with the necessity for new restrictive water management procedures [9-3].

As current variable rainfall patterns make corn a less reliable crop, sorghum has already been shown to be moving steadily northward to replace corn as a cash crop;

another background database in a state of flux. COE could develop an interagency effort with EPA, USDA, and other relevant agencies to address these issues.

COE may also want to work with the State Department with regard to beach erosion and other issues relating to sea level changes in U.S. Trust Territories around the world. As the oceans swell from warming and then increase in size due to the glacial melt process, the Marshall Islands, among many other low lying American Protectorates could gradually sink beneath the sea. A comprehensive study of all low lying areas and their value politically and militarily could be assessed.

As the global warming process continues, it will change the comfort zone of the populace that lives near major water bodies. This will cause slow shifts in population centers that could easily affect our relations with Mexico and Canada. Mexico could very easily make more demands on the U.S. for more water and grain resources; while we could do the same with our Canadian neighbors as most agricultural models show a gradual shift in optimum growth zones to the north. Critical factors to any agreements will be the issues of water resource management and population movements in an orderly manner.

A good benchmark for future attempts at international cooperation is the 1987 Montreal Protocol.

> "The protocol calls for automatic and *periodic science* reviews to allow for possible updating of its requirements. The signers will reconvene in 1990 to review the appropriateness of the protocol in the light of new observations and theory."

> "The watershed nature of the Montreal Protocol demands that we even improve on what scientists have been able to do in interacting with policy makers. While the stratospheric ozone and chlorine problem is extremely important in its own right, perhaps the most valuable lesson of the Montreal experience is an improved understanding of how the science and policy communities should interact in order to come up with a global action on a subject prior to the occurrence of unambiguously observed effects. With the greenhouse effect lying in wait for future scientists and policy makers, we need all of this kind of apprenticeship that we can get." [9-4].

When developing future protocols convening nations can essentially take three approaches to any agreement:

- Wait and See-Allocate just enough money to allow data collections and basic experiments to investigate the problem areas. It is our contention that this luxurious time of much concern with little commitment or appropriated money is rapidly ending for the G7 nations of this world. The trends for global warming, ozone depletion, increased air pollution, and gradual climate change are all in place. The only unknown centers around the degree of variability, or the intensity of the extremes to come.

- Adaptation-Convening groups of scientists, economists, engineers, politicians, and other special interest groups to work out accords such as the Montreal Protocol. Not only must these agreements be strong enough to have a measurable effect; but they must stay within reach of the signing nations so that wholesale refusal to comply with these guidelines does not become a problem for the immediate future.
- Tie-In-Strategies-Once the industrialized nations have set up basic protocols, avenues for modifying these agreements in order to include less developed countries need to be explored. An all-for-one, one-for-all strategy needs to be developed for the common good. Third world countries, especially, will need unique solutions in order to allow their return of national pride without sacrificing their promising economies in the name of world benefits.

An approach that is being tried in Brazil centers around saving acres of rain forest by selling control of the vegetation to interested parties that will then assume a percentage figure of Brazil's chronic world debt. The Brazilians see immediate positive relief and the worldwide concern over the destruction of the Amazon rain forest sees immediate dividends. Trees are kept alive to continue the photosynthesis cycle which helps slow down the injection rate of $CO_2$ into the atmosphere.

China and its growing population base, along with its growing industrial complex, needs as much economic and scientific aid as is possible to prevent a repeat of the western world's Industrial Revolution that was so dependent on fossil fuels. In the case of China, it has the world's largest deposits of fossil fuels (coal). The willful release of that $CO_2$ needs to be avoided, while still allowing China to grow as a viable, economically sound nation.

A third area of concern is the "developed" nations themselves. It is their economic development which has led to the potential disaster from the hole in the Ozone layer. Though international efforts have occurred to curb past mistakes, such as the eliminating the manufacture of CFC's and their release into the atmosphere, there are undoubtedly other products and activities which occur at the expense of the environment. The international cooperative effort by developed nations needs to continue for us to have a better understanding of our environment and how it is changing. This heightened awareness and knowledge could then be passed to developing countries so that they can avoid the environmental pitfalls previously encountered. Dying zones, such as those being uncovered in Eastern Europe [9-5], must be prevented from occurring in other areas of the world. Developing countries need to be encouraged to merge their economic growth with environmental concerns.

Developing countries need incentives in order to not do things the "old fashioned way", but in a manner that will produce positive results for their forests and their agricultural needs. Their water management procedures should gradually improve their water volume, clarity, PH indices, and keep salinity due to irrigation from increasing at an unhealthful rate. In times of stress (i.e. global warming) water rights become a powerful weapon.

If the G7 countries do not help the developing nations to cope with climate change, then the battle over the effects of global warming will still be lost. The old methods that developing nations rely on for economic stability are essentially based on systems that release known pollutants such as $CO_2$, CO, NOH radicals, and trace acids into the air, water, and ground. Thus if we, as nations, cannot truly help each other, then the pollution problems will still win out in the end. The research efforts of the major industrialized countries have to be shared with the developing third world nations so that potential conflicts over water resources, agricultural potential, industrial techniques and growth will be handled in an expeditious manner. In the areas of "Global Climate Change", "Industrial Base or Agricultural Base", "Rich or Poor"; we need each other.

# THE POSSIBLE IMPACT OF GLOBAL CLIMATE CHANGE ON THE US ARMY CORPS OF ENGINEERS

The commitment of the Corps of Engineers (COE) to the Department of Army (DA) is stated in Army Regulations listed in Table 13. The COE's concern of environmental issues is influenced by several specific regulations within table 13. Of immediate concern, i.e. 50-100 years, would be the areas that involve the effects of ocean warming, and increased variability in short term weather patterns. Other related concerns revolve around possible philosophical and procedural changes in the management of inland water resources, developing plans and procedures to handle changes in air quality and pollution levels, and an increased effort in the public relations area to gain congressional and public trust for new initiatives to alleviate future problem areas.

Table 13: US Army regulations for the Corps of Engineers.

| Army Regulation | Title of the Regulation |
|---|---|
| AR 10-5 | Organization and Funtions Department of the Army |
| AR 10-6 | Organization and Functions Branches of the Army |
| AR 10-7 | US Army Research Institute for the Behavorial and Social Sciences |
| AR 115-1 | Climatic, Hydrological and Topographic Services Point Weather Warning Dissemination |
| AR 115-10 | Meteorological Support for the US Army |
| AR 115-11 | Army Topography |
| AR 115-12 | US Army Requirments for Weather Service Support |

In the area of ocean warming, the consensus of opinion of the scientists gathered at the American Meteorological Society (AMS) meeting in Anaheim, California, and those assembled at the regional conference in Charleston, South Carolina was for a 1 meter rise in sea level. This rise was attributed to the expansion of global ocean waters from a 1°C to 2°C rise in average global temperature over the next century. Since 1900 thermal expansion has accounted for a 4" rise in ocean levels. This in turn will significantly alter the shape of barrier beaches or cause them in some cases to disappear completely [10-1]. Plans need to be formulated for the expected rise in mean sea level for the 23 states that have federal properties on their coastlines. Several major coastal cities that may be threatened by this sea-level rise include New Orleans, New York City, and San Francisco. The tendency to use up water and natural gas deposits under cities built up over ancient alluvial plains need to be addressed [10-2]. "Rates of natural or endogenic subsidence rarely exceed 10mm per year, whereas man-induced or exogenic subsidence may be over 50mm per year." [10-2]. Houston, Galveston, and New Orleans immediately come to mind as areas where median ocean rises and subsidence trends will quickly present problems if methods are not formulated for slowing and then stopping our own artificial subsidence rates.

The increase in temperatures of adjacent ocean waters in a shorter time frame will, unfortunately, couple well with the fact that hurricane activity often conforms to a 13 year period that follows the known sunspot cycle. Since a "sunspot high" is currently ending, the probability of increased hurricane activity with stronger individual storms poses an increased threat over the next 10 to 20 years. In other words, Hurricane Hugo caused about $1.5 billion in damages to Charleston, South Carolina. The totals for Hugo in September 1989 reached $7 billion with 41 reported deaths. The strongest winds in a North Atlantic tropical cyclone belong to Hurricane Gilbert at 185 mph in September 1988 [10-3]. Far greater economic disasters and loss of human life could be experienced if a category IV (in excess of 156 mph) hurricane hits the Richmond to Boston corridor. Not only is there concern about the intensity of a single tropical cyclone, but also the number of tropical cyclone hits over the same area in the same season. It may be possible for 2 or 3 tropical cyclones to hit the Richmond to Boston corridor, or the Galveston to New Orleans crescent and cause as much damage as a single category IV hurricane. As recently as 1985 the contiguous United States reported six hurricanes in one year. Thus with an increased heat budget, and a naturally recurring storm cycle, contingency plans should be formulated as quickly as possible for the role of ETL in support of the COE's role as stated in AR 10-5 under 2-33.

Another related threat with ocean warming is the gradual change in precipitation patterns. More moisture in one watershed, less in the next, will change erosion patterns. Changing erosion cycles from industry and from farm lands coupled with the shock effect of hurricane damage will significantly alter potable coastal water sources with saltwater intrusions. Coastal areas of New Jersey and Louisiana are already affected in this manner. The effect can't be stopped, but better management practices can certainly slow its advance until suitable alternative water sources can be found.

The abundance or lack of potable water will effect where people will live and work, thus further effecting natural silt patterns that will effect COE operations for systematic dredging operations.

Another characteristic of ocean warming is the increased variability of precipitation associated with an enhanced Southern Oscillation-El Nino or its opposite effect La-Nina (as defined in Section IV). The strongest example of the Southern Oscillation - El Nino event to date is the 1982-83 occurrence. "Noteworthy is the shift in the convective region from the Australasia region to the central and eastern Pacific with subsidence and dry weather over Africa, the Indian Ocean, and Australasia. The disruption of the rainfall regime around the equatorial belt was of historic proportions. The next six months saw disastrous flooding in southwest Ecuador and northwest Peru, where many stations recorded well in excess of 2000 mm of rain for the six months. Also associated with this global shift in the tropical circulation was widespread drought in eastern and southern Africa, Sri Lanka, the Philippines, Indonesia, and Australia. In French Polynesia, where hurricanes are rare, this event was associated with five hurricanes." [10-4].

From a worldwide scope, a change to a North American analysis shows the same type of variability on a regional scale. Due to a shift of the prevailing westerlies to a zone several degrees "south of normal", the winter of 1983-1984 was noted for severe cold and excessive snow cover in the early winter months over North America (particularly the eastern half of the United States). Periods of heavy rain were noted along the Washington - California coastline. This period of storm patterns also produced several areas of significant beach erosion. This in turn allowed few snowmaking events in the intermountain region. Thus leading the area into a winter drought situation that was only, momentarily relieved by a cool, wet June; before record breaking heat and dryness prevailed through out most of the country during July and August.

Thus the warmer the atmosphere becomes, the more the ocean waters will try to adapt. The warmer the oceans become, the stronger an El Nino event will become, the more damage control will be needed from beach erosion and flooding. Conversely in drought areas more problems with waterways needing flood control and/or dredging operations (particularly in shallow areas such as Lake Michigan and Lake Erie) will have to be addressed.

This data can be deceptive. The temperature means for each season may be changing only by very small increments, but the extremes of highs and lows and precipitation values may set new records. The eastern United States winter of 1989-1990 had average values; but December 1989 was the coldest on record. January and February 1990 were the second and third warmest on record. March 1990 from the 12th through the 15th produced over 300 record highs in the eastern United States. Most of these records weren't just broken by 1-3 degrees, but rather they were shattered by 10-15 degrees. Then barely 48 hours later, the same areas were watching 2" to 10" snowfall patterns develop over their region. Thus constant revisions of background data bases will have to be accomplished to maintain accuracy for planning scenarios. As temperature values change, so too, will snow and rain amounts as well as their distribution patterns. Revised planning models will have to be formulated to account for this on-going shift under GCC. Known flood plain problems will vanish as new ones develop; and the size and scope of avalanche control projects will have to grow and change to fit the new precipitation patterns.

These new patterns will then affect the COE in its responsibilities to keep coastal waterway channels open while increased dredging operations will be the norm for inland waterways such as the Missouri-Mississippi complex, the Tennessee Valley Authority (TVA) system, and ore freighter routes through the Great Lakes. Increased dredging operations to compensate for lower annual precipitation values will increase the probability of work crews being exposed to hazardous silt deposits.

What guidelines are in place will need to be revised to account for farming interests demanding more irrigation time or larger volume flow per set time to alleviate drought conditions [10-5]. This demand on inland water resources will have to be counterbalanced by the objective of keeping the waterways open to commerce.

Downtime on channels and waterways can mean low water levels, or it can mean colder temperatures causing restrictive ice conditions. The unusual conditions during the winter of 1983-1984 may become the norm in 20-30 years. Thus new techniques for controlling ice growth that will help keep waterways open should be investigated.

As global warming slowly takes effect, the reaction of ocean warming and the resultant changes in precipitation patterns will also have an effect on regional pollution levels and air quality [10-6]. As noted in the winter of 1983-1984, a result of this El Nino was the marked increase in blocking ridges at the mid-Atlantic levels. Stagnant air masses over large urban areas such as the Richmond to Boston corridor can quickly change pollution levels to extreme values in 72-96 hours. Even more subtle changes due to Mid-West drought conditions will cause more particulate matter to remain suspended as precipitation patterns change.

This in turn will cause changes in bench mark optical guidance systems; thus causing changes in basic tactics and in use of material in either a training or actual conflict situation. Trees and grasses have been shown to be highly sensitive to adverse air quality changes; therefore background terrain data scenarios will have to be updated [10-7]. Quality assurance procedures for the upkeep of state-of-the-art weaponry will have to be revised in order to take into account the increased corrosive values of higher pollution levels and resultant adverse changes in air quality as acid rain events become more the norm instead of the rare event. Several of the more recent rainstorms to pass through the Washington, D.C. area have shown PH values between 3.3-3.6. This is quite similar in value to tomato juice [10-8]. Such high levels of acidity in rain can have a profound impact on the effectivness and longivity of equipment exposed to such elements.

Several proposals within ETL have already been formulated to address several environmental issues, including:

1. Water Resources

- Assess vulnerability of river basins/water resources systems
- Adapt water use/demand forecasting techniques
- Develop alternative climate scenarios for future analysis
- Socioeconomic impacts of water resources related to climate changes

2. Sea Level Rise Impacts

- Conduct survey of potential vulnerability of coastal beaches
- Develop planning scenarios for evaluation of projected sea level rise analysis
- Analyze range of anticipated socioeconomic impacts of sea level rise
- Evaluate potential economic impact on future commercial and recreational resource uses

3. Global Climate Model Applications

- GCM results coupled with existing COE water models
- Cost analysis of various hardware/software mixes (i.e. $100,000/run)

All of the above possibilities imply that changes are coming. The climate may slowly change, and therefore procedures for planning contingencies and for day-to-day work loads will change. Yet over the next half-century a lot of change is coming. Some will be subtle like the gradual 2$^{o}$C rise in temperature; or the 1 meter rise in the ocean's level due to heating. Some will be dramatic as in another hurricane Hugo hitting the deep South or the Eastern seaboard. We need to be ready. That means preparation, studies, the right men and material. It means more appropriations. The COE needs to promote itself in order to win the public's confidence; and the congress's trust in order to obtain appropriations in an era of shrinking budget requests. The planning must be accomplished in an orderly manner. With public and congressional trust in place, the COE will be able to do its future tasks in a more reasoned, assured, confidant manner.

# CONCLUSIONS

Global climate change is a topic replete with heated debate. Extraordinary research efforts are now underway on the subject of climate change, but much is still unknown. The debate on the direction climate change will take has itself shifted in recent years from a cooling trend and a new ice age, to a warming trend due to an enhanced greenhouse effect.

Unfortunately, there is no clear record that positively demonstrates that Earth is warming as a result of an enhanced greenhouse effect. There is, however, a smoking gun. The temperature record shows that warming has occurred over the past century on the order of 0.5$^{o}$ C to 0.7$^{o}$ C, though this change is within the realm of natural variation. There is also an increase in the concentration of greenhouse gasses in the atmosphere. Some of these gasses have residence times that exceed 100 years in the atmosphere, so their influence will extend over generations. Some gasses not only fuel the greenhouse effect, but also deplete the ozone layer which could have a disastrous effect on the biosphere. Finally, there are the simulations run on GCMs that consistently point to a warmer climate based on present trends in pollution, deforestation, and other factors (though the GCMs differ on the magnitude of this change).

GCMs are our blurry looking glass into the future and enable us to estimate impacts from possible changes in climate during the coming decades and century. The models are limited from providing forecasts on climate change for several reasons. The lack of knowledge in key processes that directly influence climate (such as clouds and the oceans), insufficient computer power to run highly sophisticated models in a timely manner, and a lack of data to support these higher order models are just some of the reasons for these limitations of the GCMs.

Nevertheless, simulations of future climate have been run based on the physical processes that are known in Earth's climate system, and in a doubled $CO_2$ environment. These simulations run on several GCMs show that the world's average surface temperature should warm from between 0.2$^{o}$ C to 0.5$^{o}$ C. Scenarios have been developed by coupling higher resolution models to the GCM output. These scenarios demonstrate how this country, as well as the rest of the world, could suffer significant hardships from a warming climate. Adjustments in present agriculture practices, protection measures for coastline communities, renovating and building new waterway systems may all be required if the world's climate changes as is now predicted for the next century. An extremely unfortunate situation may occur if the rate of change in warming suddenly increases. The ability of developed countries to cope and attempt to adapt to the change will be severely taxed. Developing and undeveloped countries, on the other hand, may have no capacity to deal with sudden changes in their environment and will suffer greatly under the stresses associated with climate change.

Considerable research effort is underway nationally and internationally to better understand and model the Earth system, and to determine just how climate will change in the next 100 years. The Bush administration has budgeted almost two billion dollars to research GCC. There are also efforts being made to raise the level of cooperation among countries to a higher plain to slow or prevent further damage to the Earth system.

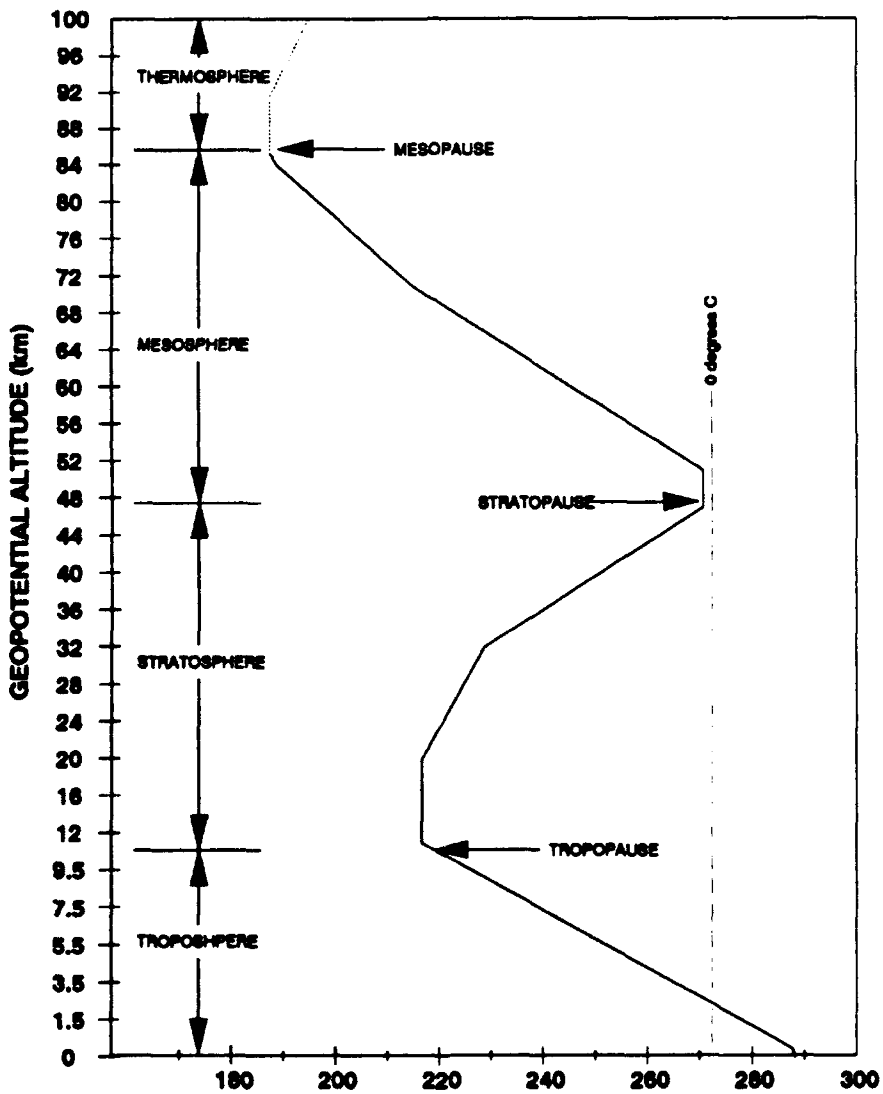
The task ahead for the Corps of Engineers is not an easy one. There are many broad reaching issues that need to be resolved very soon. Some issues that may require immediate attention include the handling and storage of toxins that now coat the bottom of many of our harbors, the development of waterway systems to support present and planned communities, and where or if coastal levees and barriers should be constructed to protect existing structures.

Global warming is not an event that has a 100% chance of happening, but there are indications that warming will occur this century. The rate and magnitude of change are difficult to ascertain due to the limitations of the GCMs, and the dependency on human activities and the level at which they either further harm or clean up the environment.

At present there is no firm ground on which to assign risks and assess impacts from changes in the climate system. But ignoring or delaying any action may cause long lasting or irreparable damage to segments in the Earth system. There are examples of how human activities can adversely influence the Earth system. The ozone layer offers one such example of how far reaching our influence is.

The environmental disasters at Krachow, Poland or Bitterfield, Germany can happen anywhere, particular in those regions that are competing for economic parity with developed countries. Their lack of interest or sophistication in environmental matters could effectively cancel any conservation efforts the U.S. or other developed nations implement. It is therefore important that sharing of technologies be incorporated into any plans of actions, such as a generous lend-lease program for the underdeveloped and undeveloped countries.

# APPENDIX




Appendix A: U.S. standard atmosphere, 1976.

Appendix B: Temperature conversion table.

| Kelvin | Celsius | Fahrenheit | Kelvin | Celsius | Fahrenheit | Kelvin | Celsius | Fahrenheit |
|---|---|---|---|---|---|---|---|---|
| 171 | -102 | -151.6 | 205 | -68 | -90.4 | 239 | -34 | -29.2 |
| 172 | -101 | -149.8 | 206 | -67 | -88.6 | 240 | -33 | -27.4 |
| 173 | -100 | -148.0 | 207 | -66 | -86.8 | 241 | -32 | -25.6 |
| 174 | -99 | -146.2 | 208 | -65 | -85.0 | 242 | -31 | -23.8 |
| 175 | -98 | -144.4 | 209 | -64 | -83.2 | 243 | -30 | -22.0 |
| 176 | -97 | -142.6 | 210 | -63 | -81.4 | 244 | -29 | -20.2 |
| 177 | -96 | -140.8 | 211 | -62 | -79.6 | 245 | -28 | -18.4 |
| 178 | -95 | -139.0 | 212 | -61 | -77.8 | 246 | -27 | -16.6 |
| 179 | -94 | -137.2 | 213 | -60 | -76.0 | 247 | -26 | -14.8 |
| 180 | -93 | -135.4 | 214 | -59 | -74.2 | 248 | -25 | -13.0 |
| 181 | -92 | -133.6 | 215 | -58 | -72.4 | 249 | -24 | -11.2 |
| 182 | -91 | -131.8 | 216 | -57 | -70.6 | 250 | -23 | -9.4 |
| 183 | -90 | -130.0 | 217 | -56 | -68.8 | 251 | -22 | -7.6 |
| 184 | -89 | -128.2 | 218 | -55 | -67.0 | 252 | -21 | -5.8 |
| 185 | -88 | -126.4 | 219 | -54 | -65.2 | 253 | -20 | -4.0 |
| 186 | -87 | -124.6 | 220 | -53 | -63.4 | 254 | -19 | -2.2 |
| 187 | -86 | -122.8 | 221 | -52 | -61.6 | 255 | -18 | -0.4 |
| 188 | -85 | -121.0 | 222 | -51 | -59.8 | 256 | -17 | 1.4 |
| 189 | -84 | -119.2 | 223 | -50 | -58.0 | 257 | -16 | 3.2 |
| 190 | -83 | -117.4 | 224 | -49 | -56.2 | 258 | -15 | 5.0 |
| 191 | -82 | -115.6 | 225 | -48 | -54.4 | 259 | -14 | 6.8 |
| 192 | -81 | -113.8 | 226 | -47 | -52.6 | 260 | -13 | 8.6 |
| 193 | -80 | -112.0 | 227 | -46 | -50.8 | 261 | -12 | 10.4 |
| 194 | -79 | -110.2 | 228 | -45 | -49.0 | 262 | -11 | 12.2 |
| 195 | -78 | -108.4 | 229 | -44 | -47.2 | 263 | -10 | 14.0 |
| 196 | -77 | -106.6 | 230 | -43 | -45.4 | 264 | -9 | 15.8 |
| 197 | -76 | -104.8 | 231 | -42 | -43.6 | 265 | -8 | 17.6 |
| 198 | -75 | -103.0 | 232 | -41 | -41.8 | 266 | -7 | 19.4 |
| 199 | -74 | -101.2 | 233 | -40 | -40.0 | 267 | -6 | 21.2 |
| 200 | -73 | -99.4 | 234 | -39 | -38.2 | 268 | -5 | 23.0 |
| 201 | -72 | -97.6 | 235 | -38 | -36.4 | 269 | -4 | 24.8 |
| 202 | -71 | -95.8 | 236 | -37 | -34.6 | 270 | -3 | 26.6 |
| 203 | -70 | -94.0 | 237 | -36 | -32.8 | 271 | -2 | 28.4 |
| 204 | -69 | -92.2 | 238 | -35 | -31.0 | 272 | -1 | 30.2 |

| Kelvin | Celsius | Fahrenheit | Kelvin | Celsius | Fahrenheit | Kelvin | Celsius | Fahrenheit |
|---|---|---|---|---|---|---|---|---|
| 273 | 0 | 32.0 | 307 | 34 | 93.2 | 341 | 68 | 154.4 |
| 274 | 1 | 33.8 | 308 | 35 | 95.0 | 342 | 69 | 156.2 |
| 275 | 2 | 35.6 | 309 | 36 | 96.8 | 343 | 70 | 158.0 |
| 276 | 3 | 37.4 | 310 | 37 | 98.6 | 344 | 71 | 159.8 |
| 277 | 4 | 39.2 | 311 | 38 | 100.4 | 345 | 72 | 161.6 |
| 278 | 5 | 41.0 | 312 | 39 | 102.2 | 346 | 73 | 163.4 |
| 279 | 6 | 42.8 | 313 | 40 | 104.0 | 347 | 74 | 165.2 |
| 280 | 7 | 44.6 | 314 | 41 | 105.8 | 348 | 75 | 167.0 |
| 281 | 8 | 46.4 | 315 | 42 | 107.6 | 349 | 76 | 168.8 |
| 282 | 9 | 48.2 | 316 | 43 | 109.4 | 350 | 77 | 170.6 |
| 283 | 10 | 50.0 | 317 | 44 | 111.2 | 351 | 78 | 172.4 |
| 284 | 11 | 51.8 | 318 | 45 | 113.0 | 352 | 79 | 174.2 |
| 285 | 12 | 53.6 | 319 | 46 | 114.8 | 353 | 80 | 176.0 |
| 286 | 13 | 55.4 | 320 | 47 | 116.6 | 354 | 81 | 177.8 |
| 287 | 14 | 57.2 | 321 | 48 | 118.4 | 355 | 82 | 179.6 |
| 288 | 15 | 59.0 | 322 | 49 | 120.2 | 356 | 83 | 181.4 |
| 289 | 16 | 60.8 | 323 | 50 | 122.0 | 357 | 84 | 183.2 |
| 290 | 17 | 62.6 | 324 | 51 | 123.8 | 358 | 85 | 185.0 |
| 291 | 18 | 64.4 | 325 | 52 | 125.6 | 359 | 86 | 186.8 |
| 292 | 19 | 66.2 | 326 | 53 | 127.4 | 360 | 87 | 188.6 |
| 293 | 20 | 68.0 | 327 | 54 | 129.2 | 361 | 88 | 190.4 |
| 294 | 21 | 69.8 | 328 | 55 | 131.0 | 362 | 89 | 192.2 |
| 295 | 22 | 71.6 | 329 | 56 | 132.8 | 363 | 90 | 194.0 |
| 296 | 23 | 73.4 | 330 | 57 | 134.6 | 364 | 91 | 195.8 |
| 297 | 24 | 75.2 | 331 | 58 | 136.4 | 365 | 92 | 197.6 |
| 298 | 25 | 77.0 | 332 | 59 | 138.2 | 366 | 93 | 199.4 |
| 299 | 26 | 78.8 | 333 | 60 | 140.0 | 367 | 94 | 201.2 |
| 300 | 27 | 80.6 | 334 | 61 | 141.8 | 368 | 95 | 203.0 |
| 301 | 28 | 82.4 | 335 | 62 | 143.6 | 369 | 96 | 204.8 |
| 302 | 29 | 84.2 | 336 | 63 | 145.4 | 370 | 97 | 206.6 |
| 303 | 30 | 86.0 | 337 | 64 | 147.2 | 371 | 98 | 208.4 |
| 304 | 31 | 87.8 | 338 | 65 | 149.0 | 372 | 99 | 210.2 |
| 305 | 32 | 89.6 | 339 | 66 | 150.8 | 373 | 100 | 212.0 |
| 306 | 33 | 91.4 | 340 | 67 | 152.6 | | | |

# SELECTED ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAAS | American Association for the Advancement of Science |
| CCM | Community Climate Model |
| CEES | Committee on Earth and Environmental Sciences |
| CEQ | Council of Environmental Quality |
| CES | Committee on Earth Sciences |
| CFC's | Chlorofluorocarbons |
| COE | Corps of Engineers |
| DMS | Dimethylsulphide |
| DOA | Department of the Army |
| DOC | Department of Commerce |
| DOE | Department of Energy |
| DOI | Department of Interior |
| DOS | Department of State |
| DOT | Department of Transportation |
| ENSO | El Nino, Southern Oscillation |
| EOS | Earth Observing System |
| EOSDIS | EOS Data and Information System |
| EPA | Environmental Protection Agency |

| | |
|---|---|
| ERBE | Earth Radiation Budget Experiment |
| ESA | European Space Agency |
| ETL | Engineer Topographic Laboratories (After October 1991 the name was changed to Topographic Engineering Center) |
| FCCSET | Federal Coordinating Council for Science, Engineering, and Tech. |
| GCC | Global climate change |
| GCM | General circulation models |
| GCRP | Global Change Research Program |
| GFDL | Geophysical Fluid Dynamics Laboratory, NOAA |
| GISS | Goddard Institute for Space Studies, NASA |
| HCN | Historical Climatology Network |
| IGBP | International Geosphere-Biosphere Program |
| IPCC | Intergovernmental Panel on Climate Change |
| JPL | Jet Propulsion Laboratory |
| NASA | National Aeronautics & Space Administration |
| NCAR | National Center for Atmospheric Research |
| NCDC | National Climatic Data Center |
| NOAA | National Oceanic and Atmospheric Administration |
| NSF | National Science Foundation |
| OMB | Office of Management and Budget |
| OSTP | Office of Science and Technology Policy |
| OSU | Oregon State University |
| PPMV | Parts Per Million Volume |

| | |
|---|---|
| SOI | Southern oscillation index |
| SRB | Sulfate reducing bacteria |
| UKMO | United Kingdom Meteorological Office |
| USACE | U.S. Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USGCRP | United States Global Change Research Program |
| UVB | Ultraviolet radiation |
| WCRP | World Climate Research Program |

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